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PENNSYLVANIA
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FOURTH SERIES
BULLETIN M 7

Limestones of Pennsylvania

By

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HARRISBURG, PA.

1925

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LIMESTONES OF PENNSYLVANIA

By Benjamin LeRoy Miller

CHAPTER I.

CHARACTER, ORIGIN, AND USES OF LIMESTONE.

DEFINITION

Chemical and mineralogical composition.—A limestone is a sedimentary rock, normally white to light gray or buff in color, composed primarily of calcium carbonate ($CaCO_3$) and occurring in the form of beds or strata of considerable uniformity and areal extent. The use of any particular limestone depends almost entirely upon its chemical and mineralogical composition. For each of the numerous uses a particular type of stone is either necessary or preferable. The composition may vary from bed to bed in the same quarry or in certain places within the same bed. Naturally uniformity in the composition of the rock increases its value, although quarries in Pennsylvania in which two or more kinds occur, thus necessitating careful sorting as the rock is quarried, have been worked with profit.

The constituents of a limestone may be either amorphous or crystalline. If crystalline, the size of the particles may be large enough to permit ready determination of the individual minerals, although this is unusual except in limestones that have undergone a high degree of metamorphism. In most cases a microscopic examination of thin sections or a chemical analysis is necessary to definitely determine the composition.

Of the chemical constituents, the carbonates are most abundant with calcium carbonate, or calcite, predominating. In some of the best limestone districts of Pennsylvania the run-of-quarry rock will average from 95 to 98 per cent $CaCO_3$. Dolomite, $CaMg(CO_3)_2$, is the second mineral in order of importance and in eastern and central Pennsylvania is almost as common as calcite. Analyses of limestone show a variation in the amount of magnesium carbonate ranging from zero to 45.65 per cent, the theoretical amount present in the dolomite molecule, and even more in certain cases where some magnesite ($MgCO_3$) is present. Rocks containing from 93 to 100 per cent of $CaCO_3$ are commonly designated as high-calcium limestones, from 7 to 20 per cent of $MgCO_3$ as low-magnesium limestones, and from 20 to 45 per cent $MgCO_3$ as high-magnesium limestones or dolomites. The amount of $MgCO_3$ present in limestone is of great importance in the economic uses of the stone, as discussed on a later page.

The relative amounts of $CaCO_3$ and $MgCO_3$ present can be roughly determined by the ease with which cold dilute hydrochloric (muriatic) acid produces effervescence. A high-calcium or low-magnesium limestone effervesces vigorously and the high-magnesium varieties scarcely at all, unless the rock is pulverized, although effervescence may be heard faintly if the specimen is held close to the ear.

On weathering, a high-magnesium limestone becomes chalky white in color and on layers of different composition the differences in color due to the variations in the amount of $MgCO_3$ present are striking. In certain localities the high- and low-magnesian strata are somewhat different in color in the unweathered rock with a greater tendency to a gray color in those with a higher content of $MgCO_3$. In a region where the rocks have been slightly metamorphosed those beds containing considerable $MgCO_3$ are apt to be more coarsely crystalline than the ones with a lesser amount. These criteria for the determination of the composition of limestones are frequently of value in field examinations although admittedly the conclusions are only approximations. Some interesting results have been obtained in the differentiation of calcite and dolomite in thin sections or as polished slabs by means of different kinds of stains.[1]

Iron carbonate ($FeCO_3$) forming the mineral siderite is a common constituent of limestones. Its almost universal presence in limestones is indicated by the invariable red or yellow color of the residual clays formed from limestones. The coloring matter in these clays is iron oxide resulting mainly from the decomposition of the siderite, although some of it may be derived from pyrite. A less common iron carbonate is ankerite $CaFe(CO_3)_2$, sometimes called the iron dolomite because it is related in the same way to $CaCO_3$ as is dolomite. Seldom can siderite or ankerite be detected in a massive fresh limestone but on careful observation cavities containing crystals of these minerals may usually be found in limestones in which they are present.

Quartz (SiO_2) is a fairly common mineral in limestones, either as an original constituent or developed by secondary action. When present in small amounts it may not be observable, but careful chemical analysis of almost any limestone will show its presence. In some rocks the proportion of quartz and calcite is so nearly equal that they may equally well be termed calcareous sandstone or siliceous limestone. Secondary vein quartz and quartz crystals in cavities are abundant in some of our Paleozoic limestones; the siliceous matter may have been derived from the limestones themselves or from associated rocks. Flint nodules and lenses are common in the Cambro-Ordovician limestones. The dense black variety is most abundant but in places it is almost milky white. Flint tends to occur in lenses ranging from ½ inch to 5 or 6 inches thick and from a few inches to several feet long, the elongations parallel to the bedding planes. When the limestone decomposes, the flint remains as part of the residual soil. It owes its origin to the secondary concentration of siliceous material by underground water and the replacement of the limestone.

---

[1] [illegible]

The amount of silica present in limestone is of great economic significance, particularly if it is desired to use the limestone for fluxing purposes, where a low silica content is demanded. Often limestone for metallurgical use is analyzed for the silica content alone.

A number of silicate minerals besides quartz may occur in limestone. The most common are the hydrous silicates of aluminum, of which more than a dozen have been described. Kaolinite ($H_4Al_2Si_2O_9$) or $(H_2O)_2\ Al_2\ O_3\ (SiO_2)_2$ the principal mineral in clay, is by far the most common. When these silicate minerals are present in large quantity the limestone is designated as argillaceous limestone and in still larger quantity as calcareous shale. Argillaceous limestone is of special importance in the manufacture of Portland cement and Pennsylvania is fortunate in the possession of certain strata in which the proportions of aluminous silicates and calcium carbonate almost exactly conform to the requirements for this purpose.

In those limestones that have undergone metamorphic action a great variety of silicate minerals may be developed, but only the more common ones will be mentioned. The most abundant one in the limestones of Pennsylvania is sericite (called damourite in the reports of the Second Geological Survey of Pennsylvania). In some cases it has been mistaken for talc. Sericite [$H_2KAl_3(SiO_4)_3$] is a variety of muscovite that occurs along bedding planes of the limestone in the form of overlapping flakes so small as to be individually indistinguishable. In the sunlight the surface so covered has a silvery sheen resembling satin. It has been formed from argillaceous materials by the process of dynamic metamorphism and is especially prominent in the more highly argillaceous limestones. The Cambro-Ordovician limestones of eastern and central Pennsylvania contain much sericite.

Tremolite [$CaMg_3(SiO_4)_3$] is a colorless fibrous mineral common in the pre-Cambrian limestones of the State, especially in those near Easton. It is a metamorphic mineral and is present only in those limestones that have undergone intense metamorphism. It is formed from siliceous magnesian limestone. In certain places it constitutes the major part of the rock. On decomposing it forms talc, serpentine, and calcite, all of which minerals are well developed in the Easton locality.

Garnets are apt to be developed where limestone has been intruded by igneous material. In Pennsylvania we have few occurrences of these contact metamorphic minerals. The best example is in the

Cornwall iron ore mines where a diabase dike has intruded a compact dolomitic limestone. In one part of the mine garnets of the andradite [$Ca_3Fe_2(SiO_4)_3$] variety are occasionally found.

Small crystals of both orthoclase and plagioclase feldspars have also been noted in the limestone, especially in the metamorphic varieties. Clarke[2] gives a long list of minerals, mainly silicates, that may develop in metamorphic limestones. Among them are scapolite, wollastonite, epidote, corundum, ruby, magnetite, hematite, vesuvianite, zoisite, gehlenite, biotite, phlogopite, periclase, brucite, forsterite, olivine, enstatite, hypersthene, numerous amphiboles and pyroxenes, apatite, fluorite, rutile, titanite, etc. A number of these have been identified in the highly metamorphosed pre-Cambrian limestones of the State but in amounts so small as to be of little importance except to mineralogists.

Graphite in thin flakes is abundant in the pre-Cambrian metamorphosed limestones of the State but unlike somewhat similar Canadian occurrences has never been utilized. Instead the graphite production of Pennsylvania has all been derived from graphitic schists or gneisses which are so intimately associated with these limestones in several places that they are regarded as a single formation. The graphite particles seem to have been formed by the metamorphosis of carbonaceous matter originally present in the sediments.

Among the sulphides in limestone, pyrite (FeS_2) is the most common. Practically all of the sulphur in limestone is combined with iron as pyrite. In argillaceous limestone, sulphur may be abundant and easily recognized but in the purer limestones it may not be observed even though a chemical analysis shows its presence. On the other hand, occasional cubical crystals and nodules of pure pyrite an inch or more in diameter have been found in some of the compact, massively-bedded dolomitic limestones. Galena (PbS), sphalerite (ZnS), and chalcopyrite ($CuFeS$) have been found in our limestones, mainly in calcite veins, although in places as replacement minerals within the limestone strata. At Friedensville, Lehigh County, sphalerite ores, oxidized to calamine near the surface, occurring both as veins and replacement bodies within the Beekmantown limestone, have been extensively worked and at Bamford, Lancaster County, and Birmingham, Blair County, both sphalerite and galena ores are developed and have been mined. The same minerals have been found in several other limestone areas of the State but in insignificant amounts.

Fetid limestones, commonly called "stink stone" because of the odor produced when the stones are struck, are fairly common. The ordor is that of hydrogen sulphide (H_2S) which seems to be present as a gas in the limestones, and has probably been derived from the decomposition of some organic matter.

---

[2] Clarke, F. W., Data of Geochemistry. U. S. Geol. Surv. Bull. 616, pp. 620-623, 1916.

Color.—A pure limestone or dolomite should be perfectly white, but actually nearly all are colored by certain impurities. The color is almost entirely a result of the chemical constitution of the stone although the physical characteristics such as variations in porosity, size of grain, and degree of crystallinity may have some effect. The iron oxides, hematite, turgite, limonite, and göthite, produce the various shades of buff, yellow, pink, and even red, and carbonaceous matter is responsible for the blue, gray, and even black colors. The iron oxide colors are permanent but those due to carbonaceous materials will slowly disappear by oxidation if exposed to the action of the atmosphere. It is a very common observation that limestones become whiter on exposure and the beds at their outcrop are in most cases whiter than they are beneath the cover of soil and other strata.

Changes of color of this kind are not objectionable and do not unfit a stone for structural purposes. But limestone containing pyrite (or perhaps marcasite) is apt to weather in unsightly blotches due to the formation of limonite.

When both iron compounds and carbonaceous matter are present in a limestone, the iron is apt to exist as light-colored or colorless ferrous compounds. If by oxidation the carbonaceous substances are removed the iron passes into the ferric condition and the stone becomes buff, yellow, or reddish, depending upon the particular compound formed and the amount present. These changes are most noticeable in very dark limestone.

Hardness.—The hardness of a rock depends upon the hardness of the individual mineral particles composing it and upon the amount and character of the cementing material. Limestone is composed primarily of calcite with a hardness of 3 in Moh's scale of hardness, in which minerals are classified on a scale of 1 to 10. Dolomite is slightly harder ranging from 3.5 to 4. Both are scratched readily by a knife or a piece of glass but cannot be scratched with the finger nail.

The cementing material for practically all our limestones is either calcium or calcium-magnesium carbonate with the hardness of calcite or dolomite. The amount varies from almost zero in which the pore spaces are so numerous that the rock can be crumbled in the hand to compact rock with almost no pore space. Most of the limestones of Pennsylvania are firmly cemented, as are the older limestones generally in all parts of the world.

Texture.—The texture of a stone depends upon the size, shape and degree of crystallinity of the individual particles and also upon the quantity of the cementing material. We have fine-grained compact limestones in which the naked eye cannot detect any individual particles and the rock breaks under the hammer with a conchoidal fracture almost as perfect as in glass. This type is represented in a number of the Coal Measures limestones in the western part of the State. In other cases the particles are coarser and on a weathered surface appear much like roughened grains of sand. The cementing material may be deficient and the rock so porous that it gives forth a hollow sound when struck. The stone may be a mass of angular fragments of fossil shells either feebly or firmly cemented together by calcium carbonate. Excellent examples of this type are found in the Ames and Greenbrier limestones.

The particles may be spherules formed of concentric layers of calcium carbonate. If these particles are small the rock is called oolite because of its resemblance to fish roe, or pisolite if larger. Oolites are common in the Cambro-Ordovician limestones of the State and occasionally pisolites, with the individual spherules the size of small peas, are also observable.

In the Cambro-Ordovician and Triassic strata of Pennsylvania, there are some limestones composed of rounded to angular fragments of still earlier limestone deposits bound together by a calcareous cement. If the fragments are rounded we designate the rock as a limestone conglomerate and if angular as a limestone breccia. The fragments vary greatly in size in the same rock and in places range up to one foot or more in diameter.

As originally deposited limestone may be either amorphous or crystalline, but in the older limestones of the State we now find all the material in the crystalline condition owing to the great amount of compression and heating that they have experienced by the mountain-building forces that were so active during the pre-Cambrian and at the close of the Ordovician and Permian periods. If the crystalline grains are small and not particularly noticeable we commonly retain the name limestone, but if coarser the rock is called marble.

Structure.—The structures of rocks affect their economic utilization. Limestones, as indeed all sedimentary rocks, are found as beds or strata with great lateral extent in comparison with their thickness. They are said to be stratified or bedded. It is not unusual for a limestone bed to extend for fifteen or twenty miles with scarcely any appreciable change in its physical character or thickness. Some of the Carboniferous limestones of the State, as for example the Ames, Greenbrier, and Vanport, can be traced by outcrops and borings for upwards of a hundred miles with only slight variation in characteristics.

Limestone occurs both in thin and in thick or massive beds. The thinner ones resemble shales and are commonly called shaly limestone though they may be highly calcareous. In general, argillaceous limestone is thin bedded, the individual beds seldom more than one inch thick; the purer limestone and dolomite, in most places, occur in beds ranging from 6 inches to a few feet, seldom more than 5 feet thick; and the arenaceous limestones are apt to be massively bedded in some places ten to twenty feet thick.

In many places in the State limestone beds show lines or laminae of cross-bedding or cross-stratification. These lines are at a decided angle to the planes separating the beds, a condition that can result only where there are shifting currents in shallow water. Cross-bedding is characteristic of arenaceous limestone, such as the Loyalhanna in Westmoreland County, but it is not confined to it, as numerous fairly pure limestones of Cambro-Ordovician age are distinctly cross-bedded.

In many places the upper surface of limestone beds shows distinct ripple marks, alternating ridges and shallow troughs or grooves produced by waves when the limestone was an unconsolidated ooze or fine calcareous sediment.

Mud cracks or sun cracks such as are commonly seen where a deposit of mud is exposed to the drying action of the sun, are not rare in the limestones of Pennsylvania. They indicate that the unconsolidated calcareous sediments were at times exposed at low tide. Small pits produced by rain drops have also been preserved.

The Cambro-Ordovician limestones contain numerous beds of edgewise or intraformational conglomerate or breccia, a peculiar stone composed of thin flakes of limestone many of which stand on edge or are tilted at various angles to the bedding plane and firmly cemented by calcareous matter. On a freshly fractured surface the conglomerate character of the rock may not be noticeable but weathering removes the cementing material with greater ease and the fragments stand out in striking contrast to the normal limestones. Their origin has been explained in different ways such as (1) by submarine slipping or slumping and consequent breaking of the thin layers of partly indurated ooze, (2) by the action of the sun drying the exposed sediments at low tide and causing the thin surface layers to break loose and curl up and to be later transported and piled up by wind or wave action and (3) by wave action in shallow waters breaking the thin layers of sediments that had become cemented by calcareous matter or hardened by setting. These are the more usual, but by no means all the explanations offered for these interesting structures.

The limestones of Pennsylvania contain many fine examples of stylolites although not developed to the same extent as they are in the famous Tennessee marble or the Carthage (Missouri) marble. Stylolites are zig-zag lines resembling the sutures between the bones of the skull, and roughly parallel to the bedding planes of the stone. They are of secondary origin and have never been satisfactorily explained; probably they are caused by unequal solution and subsequent adjustment of the material within the bed by small faults.

Joints are the cracks or fissures at approximate right angles to the bedding planes by which the beds are broken into blocks. In limestones they may be produced by shrinkage due to loss of moisture (desiccation), by folding causing the rocks to break under tension, or by compression (also the result of deformation) of the strata. The joints are normally in more or less parallel series and commonly two series approximately at right angles to each other break the rocks into rectangular blocks. In this case if the joints are not too close together it is easy to secure blocks for building purposes that require little dressing. Many of the limestones of the State are so closely jointed that building stones cannot be obtained. In a quarry a few miles northwest of Lancaster the rock is broken by jointing into such small fragments that a steam shovel is operated without any preliminary blasting.

Although the limestones were originally laid in practically horizontal layers they are now much folded and broken. The folds are of all sorts and in places the strata have been broken and the parted edges displaced. These breaks are called faults. In Pennsylvania the largest known faults displaced the strata as much as 3,000 feet. The folding and faulting are especially complex east of the Allegheny Front where, by a great amount of compression, the strata in places have been folded into half or less than half the space they originally occupied. Plate VIII (p. 112) gives some idea of the complexity of these folds.

In central Pennsylvania the folds and faults make it difficult to quarry any particular bed for any considerable distance or to work it far from the outcrop because the normal steep dips carry the beds to depths that cannot be profitably worked. On the other hand in the western part of the State the outcrops of certain beds of limestone are nearly horizontal and can readily be traced. The more persistent limestone beds there form excellent horizon markers in locating the low anticlinal structures that are so important as reservoirs in the accumulation of oil and gas.

ORIGIN OF LIMESTONE.

In a discussion of the origin of limestone it is necessary to account for the primary origin of calcium and magnesium carbonate and for their concentration or segregation. In some igneous rocks there seems to be evidence of the presence of calcium carbonate as a primary mineral, but only in small amounts. The great amount of it now present in the limestone strata or in solution in bodies of fresh and salt water is certainly of secondary origin and formed by the action of water containing carbon dioxide on the calcium-bearing minerals of the igneous rocks. Calcium carbonate taken into solution has been carried into the streams and oceans where it is almost universally present. Magnesium carbonate is formed in a similar manner. Limestone and dolomite are formed by the deposition of these materials from solution.

Limestone owes its direct origin in most cases to the action of organic life. However, the same substances may be precipitated from solution by chemical processes in no way dependent upon organisms and some limestone has undoubtedly been so formed. Limestones are frequently classified with reference to origin into marine and fresh water types and in this report will be so designated. This has practical importance because of the greater uniformity and wider areal distribution of the marine strata. In the following paragraph the organic and inorganic agencies in the formation of limestone are discussed.

Organic Agencies.

A wide variety of animals and plants is concerned in the formation of limestone. These include all groups that possess the ability to extract calcium carbonate from solution and to build it into their structures as internal or external skeletons or to cause its precipitation by chemical changes consequent upon their life activities, Among animals the important groups are the mollusca (gastropods, pelecypods, cephalopods, and pteropods), brachiopods, crinoids, bryozoa, corals and foraminifera. The important plant groups are the algae and bacteria. Limestone largely composed of the remains of the mollusca and brachiopods, is termed "shell limestone", those in which the crinoids, corals, or foraminifera are abundant and easily recognizable are known as "crinoidal", "coralline", or "foraminiferal" limestone. Some limestones are named for a particularly abundant fossil, such as the "fusulina limestone", named for a genus of foraminifera that lived in great numbers in the Carboniferous period in certain seas.

Clarke and Wheeler[3] have made analyses of a number of marine invertebrates possessing calcareous parts and thus capable of forming limestone by their accumulation. The following table summarizes their results.

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[3] Clarke, F. W. and Wheeler, W. C., The Inorganic constituents of marine invertebrates; U. S. Geol. Survey, Prof. Paper No. 102, Washington, 1917.

Inorganic Constituents of Marine Invertebrates.

Name	Number of Analyses Averaged	SiO_2			$(Al,Fe)_2O_3$			$MgCO_3$			$CaCO_3$			$CaSO_4$			$Ca_3P_2O_8$		
		Avge.	High	Low	Avge.	High	Low	Avge.	High	Low	Avge.	High	Low	Avge.	High	Low	Avge.	High	Low
Foraminifera	5	4.93	15.33	0.03	1.87	4.94	0.09	7.43	11.08	1.79	85.77	89.76	77.02				Trace	Trace	0.00
Calcareous sponges	2	4.59	7.81	1.36	5.58	5.72	**5.45**	**6.69**	8.00	5.37	76.39	81.64	71.14	?	?	?	6.75	9.96	3.55
Madreporarian corals	29	0.18	1.25	0.00	0.15	0.74	0.00	0.49	1.11	0.69	99.17	99.71	97.57	0.01	0.21	0.00	Trace	Trace	0.00
Alcyonarian corals	22	1.16	18.05	0.00	0.50	5.80	0.03	11.24	15.73	0.35	82.19	98.93	52.23	2.20	5.43	Trace	2.71	13.35	Trace
Hydroids	6	0.10	0.24	0.02	0.09	0.21	0.05	0.54	1.78	0.22	98.31	99.63	96.77	0.96	1.80	0.06	Trace	Trace	Trace
Annelids	3							3.35	9.72	0.00	96.07	99.55	89.66	0.04	0.13	Trace	0.54	0.99	Trace
Crinoids (existing)	21	0.57	5.73	0.02	0.54	1.41	0.08	10.72	13.37	7.86	87.88	91.55	83.47				0.29	1.12	Trace
Fossil crinoids	10	6.21	29.30	0.24	1.38	2.66	0.28	3.43	20.23	0.80	88.06	96.07	67.24				0.02	0.20	0.00
Sea urchins	7	2.13	9.93	0.05	1.52	5.20	0.18	7.29	10.38	5.99	87.72	93.13	77.91	1.10	2.56	0.38	0.24	1.06	Trace
Star fishes	11	1.11	2.47	0.24	0.58	1.17	0.11	10.73	14.08	7.79	86.91	91.06	84.36	0.20	1.91	?	0.47	1.14	0.18
Holothurians	1	0.15			0.34			13.81			83.29			2.38			Trace		
Bryozoa	9	4.84	16.71	0.18	0.87	2.41	0.12	6.73	11.08	0.63	85.19	96.90	63.29	2.36	8.47	?	0.61	2.68	Trace
Calcareous brachiopods	5	0.23	0.52	0.06	0.23	0.48	0.04	2.42	8.63	0.49	96.10	98.61	88.59	0.83	1.72	0.36	0.19	0.57	Trace
Phosphatic brachiopods	4	0.69	0.91	0.49	0.64	1.16	0.29	2.97	6.68	0.79	4.59	8.35	1.18	5.16	8.37	2.93	82.91	91.74	74.73
Pelecypods	11	0.18	0.36	0.00	0.14	0.59	0.01	0.22	1.00	0.00	99.42	99.87	98.60				0.01	0.40	Trace
Scaphopods and amphineurans	2	0.51	0.61	0.40	0.24	0.27	0.22	0.33	0.45	0.20	98.75	99.13	98.37	0.17	0.35	?	Trace	Trace	Trace
Gastropods	20	0.52	2.26	0.00	0.34	1.89	0.04	0.29	1.78	0.00	98.73	99.95	96.60	0.02	0.20	0.00	0.10	0.85	Trace
Cephalopods	3	0.09	0.19	0.00	0.11	0.15	0.06	2.60	6.02	0.16	97.20	99.50	93.76				Trace	Trace	**Trace**
Crustaceans (barnacles)	6	0.45	2.12	0.03	0.37	0.72	0.15	1.75	2.49	0.75	97.30	99.07	95.53				0.13	0.77	0.00
Crustaceans (crabs, lobsters, shrimps)	11	0.91	3.82	0.09	0.50	1.11	0.06	8.89	15.99	4.84	69.42	82.64	28.56	2.02	5.33	0.60	18.26	49.56	6.57
Calcareous algae	20	0.60	3.50	0.02	0.34	1.62	0.01	14.04	25.17	0.02	84.16	99.21	73.63	0.80	1.39	0.03	0.06	0.43	Trace

Fossil crinoids were found in addition to contain from none to 2.21 per cent $FeCO_3$, averaging 0.82, and from none to 0.26 per cent $MnCO_3$, averaging 0.08.

The absence of recognizable organic remains in limestone must not be assumed as evidence of its inorganic origin. Shell and coral fragments may be reduced to fine grains by the action of waves and tides. Again, all traces of the organisms may be destroyed by secondary changes such as crystallization and dolomitization. Most of our marbles, especially the coarse-grained varieties, present no indication of fossils although there may be evidence that they probably were formed from highly fossiliferous strata.

Part of the calcium carbonate of the calcareous-secreting organisms exists in the form of calcite and part as aragonite. In some shells these minerals form alternating layers. Aragonite is less stable and after the death of the organism tends to pass into solution or change to calcite so that it is of little importance in our present limestones. Clark and Wheeler[4] state that their analyses of the marine invertebrates and calcareous algae show that those groups with aragonite skeletons are almost completely non-magnesian.

Foraminifera.—The foraminifera, long recognized as important rock builders, are small animals that secrete calcareous skeletons of great variety in size, shape and structure. Most of them are smaller than the head of a pin, although varieties, such as the *Nummulites* of Europe, Africa, and Asia are flat disk-like bodies ranging in size to more than an inch in diameter and are almost the only form in certain thick limestone strata. The chalk deposits of England, France and Belgium are mainly composed of small foraminiferal shells; certain limestones of Carboniferous age in this country are constituted in great part of a genus called Fusulina; and at present foraminiferal remains in which the genus Globigerina predominate, cover almost 30 per cent of our ocean basins.

Sponges.—Certain sponges having calcareous spicules or skeletons have contributed considerable material locally in the formation of limestones.

Corals.—In the warm shallow marine waters coral life is abundant and coral reefs are in process of steady growth. Early in the development of life on the earth, reef-building corals had a much wider distribution than now. Some beds of limestone in Pennsylvania are composed almost entirely of coral remains. Near Hollidaysburg a limestone quarry is being worked in one of these old coral reefs.

Hydroids.—The Paleozoic limestones of Pennsylvania contain many specimens of Stromatopora, a hydrocoralline member of the Hydrozoa. Heads of this form up to 10 feet in diameter have been found. The mass is composed of thin concentric layers that resemble the algae Cryptozoon described on a later page but showing distinctive structures on closer examination.

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[4] Op. cit., p. 52.

Crinoids.—Of the large group of the Echinodermata there are many calcareous shelled varieties belonging to the cystoids, blastoids, crinoids, star fishes and echinoids but only the crinoids constitute any considerable part of limestones. The crinoids, called sea lilies or rock lilies because of their resemblance to plants, are composed of calcareous plates that in most cases become separated in the decomposition of the organic portions of the animals. So numerous were they in some of the Paleozoic seas that limestone beds in many places are almost entirely composed of the flat hollow disks that formed their stems. They are abundant in the limestones of this State.

Bryozoa.—The bryozoa, with coral-like structures of extremely great variety, are common fossils in the limestones of the State and have contributed materially in their formation. Small, branching, tree-like varieties and flat, fan-shaped forms with numerous openings are most common.

Brachiopods.—In the Paleozoic seas these bivalve shelled animals sometimes mistaken for mollusks, lived in great numbers and variety and are the most common fossils recognized in our limestones. Their shells are in better state of preservation than most of our fossils and thus readily recognized. They are important rock builders, although it must be admitted that most of the specimens found in Pennsylvania are casts or moulds in the shales.

Mollusca.—The shelled mollusca, Pelcypods (clams, etc.) Gastropods (snails, conchs, etc.), Cephalopods (squids, cuttle fish, etc.), Scaphopods, and Amphineura (chitons) have existed since the early Paleozoic in great numbers. They lived mainly in shallow water and their shells have been tossed into piles or broken by the waves of the ocean. The accumulations compacted into limestone have been found locally in every geologic period.

Other animal groups.—Remains of other animal groups are found in our limestone, but except locally are insignificant parts of the rock. Among these are worms that secrete calcareous tubes in which they live, various crustaceans, and the great division of vertebrates.

Algae.—The agency of plants in the formation of calcareous deposits has been minimized in the past but we are now convinced that they have been of extreme importance and in many places have contributed more to the deposition of limestone than have animals. Although a number of plants are known to possess the ability to precipitate calcium and magnesium carbonates from solution the algae and bacteria seem to be the most important.

The algae thus far investigated include both fresh and salt water forms whereas the known bacteria with this power are all marine. The fresh water calcareous-secreting algae have been studied by many botanists and geologists largely because of the economic importance of the deposits formed by them. In New York, Michigan, Indiana and to a lesser degree in other States bog marl or bog lime has long been dug or dredged from existing or extinct glacial lakes and utilized in the manufacture of Portland cement and lime, or for fertilizing the soils. The investigation of the marls of Michigan[5] proved conclusively that the fresh-water *Chara* (Stonewort) were mainly responsible for the deposits although some of the blue-green algae likewise were agents of precipitation. The latter commonly form ellipsoidal pebbles with concentric radial arrangement. Probably other water plants are also concerned in the formation of marl but to a lesser degree.

The algae investigated precipitate the calcareous material in their stems and these plant structures have been detected throughout the marl deposits of Michigan. They have also been recognized in some of the Tertiary limestones underlying Paris.

The deposits of algal marl in Pennsylvania have received little attention as yet but are known to exist in a few places. In Centre County some marl of this kind has been dug for fertilizer. The chief interest to us in this type of calcareous sediments is that it suggests a probable origin of the compact, structureless fine-grained, fresh-water limestones of the upper Coal Measures of the western part of the State. These are mainly non-fossiliferous although some of them contain a few fresh-water shells just as do the Michigan marls.

Fresh-water algae are also present in streams and springs. The thick deposits of travertine about the Mammoth Hot Springs of Yellowstone Park owe their origin mainly to the action of algae, some of which are able to live in water near the boiling temperature.

Marine calcareous algae, commonly called Nullipores, are known to be of the greatest significance in the formation of limestone. There are several kinds, foremost of which are Lithothamnium, Halimeda, Diplopora, Corallina, etc. These were long known to be prominent in the formation of coral reefs but now it seems that in many cases they have contributed even more to these structures than the corals.[6] The Triassic dolomites of the Tyrolean Alps are said to have been formed mainly through the agency of algae. In the Lower Cambrian of this State we find abundant examples of calcareous algae.

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[5] Davis, C. A., Lane, A. C., Hale, D. J., Marl (Bog Lime); Geol. Surv. Mich., Vol. 8, Pt. 3, Lansing, 1903.

[6] Howe, M. A., The building of coral reefs: Science, New Ser. Vol. 35, pp. 837-842, 1912.

Cryptozoon proliferum.—These form a large part of the strata in many places in the Bethlehem region. It is not improbable that other forms of calcareous algae whose structures were less favorable for preservation may likewise have contributed to the formation of our Paleozoic limestones.

As shown in the analyses of Clarke and Wheeler on a preceding page, the structures of the marine calcareous algae are highly magnesian and this may largely account for the abundance of dolomite or rich magnesian limestone of the Cambrian and Ordovician strata of the State.

Bacteria.—In recent years considerable information has been obtained concerning the work of bacteria in the precipitation of calcium carbonate from the ocean waters, and it is now generally believed that many of our non-fossiliferous limestones owe their origin to bacterial processes.

In some of the muds near the Bahama Islands and the Florida Keys, Drew[7] found 160,000,000 specimens of *Bacterium calcis* (later determined to be *Pseudomonas calcis.*[8]) per cubic centimeter and concluded that the fine calcareous deposits of those regions had been largely formed through their activities. One method described by Kellerman and Smith is the formation of ammonia by the decomposition of proteids or by the reduction of nitrates to nitrites and to ammonia and the further formation of ammonia carbonate by reaction with carbon dioxide produced by plants or animals. In the presence of $CaSO_4$ or its ionized constituents, the following reaction would take place: $CaSO_4+(NH_4)_2CO_3=CaCO_3+(NH_4)_2SO_4$. Vaughan[9] reports that these dentrifying bacteria precipitate the calcium carbonate largely as aragonite and that it frequently tends to form small balls or spherules that by accretion become oolite grains. He believes that "all marine oolites, originally composed of calcium carbonate. of whatever geologic age, may confidently be attributed to this process."

Before the investigation of Drew, Vaughan, Kellerman and Smith, Daly[10] had formulated a hypothesis to the effect that in the pre-Cambrian and early Paleozoic seas the organic matter, both plant and animal, collected on the ocean bottoms and there decomposed, forming ammonium carbonate that reacted with the calcium and magnesium solutions to form precipitates of calcite and dolomite. Until the appearance of the fishes there were few scavengers living near the bottom and feeding on the decaying organisms there accumulating so that this agency was responsible for "a large part, if not all, of the pre-Cambrian limestones and dolomites, but as well, the limestones and dolomites of the early Paleozoic formations. This precipitation grew slower in proportion to the development of the fishes and other efficient bottom scavengers. When the scavenging system became well established calcium salts could, for the first time, accumulate in the ocean water in excess of the needs of the lime-secreting organisms. Thereafter the marine limestones have been largely formed from the debris of the hard parts of animals and plants."

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[7] Drew, G. H., On the precipitation of calcium carbonate in the sea by marine bacteria: Carnegie Institution of Washington, Publication 182, pp. 7-45, 1914.

[8] Kellerman, K. F. and Smith, N. R., Bacterial precipitation of calcium carbonate: Jour. Wash. Acad. Sci. Vol. 4, pp. 400-402, 1914.

[9] Vaughan, T. W., Preliminary remarks on the geology of the Bahamas, with special reference to the origin of the Bahaman and Floridian oolites: Carnegie Institution of Washington Publication 182, pp. 47-54, 1914.

[10] Daly, R. A., First calcareous fossils and the evolution of the limestones: Bull. Geol. Soc. Amer. Vol. 20, pp. 153-170, 1909. The limeless ocean of pre-Cambrian time: Amer. Jour. Sci. 4th Ser. Vol. 23, pp. 93-115, 1907.

The pre-Devonian limestones of the State are markedly deficient in fossils. Whether they owe their origin mainly or entirely to the action of bacteria or to the somewhat similar process discussed by Daly cannot be determined, but his interpretations seem plausible and worthy of acceptance. The limestones possess the characteristics of normal chemical precipitates but are probably attributable to organic agencies.

Inorganic Agencies.

In the past many nonfossiliferous limestones were considered purely inorganic but now are referred to some of the organic processes described above. Locally, there are deposits of calcium carbonate undoubtedly formed without any connection with organisms and in several different ways. However, in the aggregate they are of little economic importance.

When bodies of water disappear by evaporation there are formed, probably in every instance, deposits of calcium carbonate due to its almost universal presence in lake and ocean waters. In regions where the rainfall is deficient and evaporation excessive, deposits of limestone have been observed to form in river beds but only in limestone regions where the waters become highly charged with calcium carbonate. Near waterfalls calcareous precipitation is apt to form by evaporation of the spray.

Many hot springs and some cold ones heavily charged with calcium carbonate form deposits called "tufa" or "travertine" near their vents. Algae are, in some cases. responsible for the precipitation but liberation of carbon dioxide, evaporation, or cooling of the water will cause deposition.

The stalactites and stalagmites of caves are produced by evaporation and loss of the carbon dioxide responsible for holding the calcium carbonate in solution. The beautifully colored cave onyx extensively used as an interior decorative stone, originates in this way.

The precipitation of calcium carbonate from ocean water at several places especially near the mouths of rivers, has been described, and explained by purely inorganic processes involving chemical changes.

Most of these instances are not sufficiently supported by careful observations to warrant their acceptance. Calcite-secreting bacteria suggest another explanation.

ORIGIN OF DOLOMITE.

Scarcely another question of geologic inquiry has received as much attention as that concerning the origin of dolomite. French, German, Belgian, English, and American geologists have attacked the problem and scores of monographs based on observations and experiments have been written in support of one theory or another but there still remain many divergent views. A summary of the literature is impracticable in this place but the problem is of such great economic importance to the users of limestone in Pennsylvania that it cannot be ignored. Certain of our limestones are sought because of their high magnesian content and others are rejected on account of it. In some sections high and low magnesian limestones are so mixed that the stone cannot be utilized for purposes requiring either but not the other.

There is no sharp line between dolomite and limestone. Careful study of magnesian limestones seems to indicate that nearly all the magnesium present exists as part of dolomite [$(CaMg)\ (CO_3)_2$] molecules and a true dolomite rock is one in which all the calcium exists in the same form. In most cases both dolomite and calcite crystals compose the rock and seldom is either one entirely absent, although in general, rocks low in dolomite crystals are more abundant than the others. Some of our limestones may contain magnesium as uncombined $MgCO_3$ but this is not common. Analyses showing more than 45.61 per cent of $MgCO_3$, the theoretical percentage of dolomite, are rare although there are some examples of rocks containing over 50 per cent $MgCO_3$.

The theories that have been formulated present many different points of view and lead to the belief that dolomite can be produced under several conditions and in all probability has been produced in nature in different ways. Dolomite is reported to have been prepared synthetically in the laboratory by many investigators[11] but we cannot be certain that any of the processes employed have been duplicated in nature.

Under unusual conditions normal dolomite may have been formed as a primary chemical precipitate in shallow ocean water but it seems probable that most of our highly magnesian limestones owe their origin to secondary changes.

The analyses of the skeletons of various marine invertebrates and calcareous algae, given on a preceding page, show that many of the organic calcareous deposits accumulating in the seas contain considerable amounts of magnesium carbonate, especially the foraminifera, alcyonarians, echinoderms (crinoids, sea urchins, starfishes, and holothurians), crustaceans, and coralline algae. Clarke and Wheeler give an analysis of a species of algae, *Goniolithon strictum*, from Soldiers Key, Florida, which contained 25.17 per cent $MgCO_3$. In their studies they found that the forms living in warm waters had a higher percentage of magnesium, a condition which seems to be general in the different groups and may indicate that our dolomitic limestones were largely formed in the warm waters of the Paleozoic seas.

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[11] Clarke, F. W., Data of Geochemistry: U. S. Geol. Surv. Bull. 616, pp. 559-563, Washington, 1916. Van Tuyl, F. M., Origin of Dolomite: Iowa Geol. Surv., Vol. 25, pp. 251-421, Des Moines, 1916.

Those organisms that have aragonite as part of their skeletons form deposits that favor dolomitization because that mineral is more soluble than calcite.

Unless organisms in the past had the ability to extract from ocean water a larger amount of magnesian salts than is possessed by forms living now, it is evident that secondary action has been involved in the formation of our magnesian limestones, inasmuch as numerous strata contain more than 40 per cent $MgCO_3$. The secondary change may have been enrichment either by the removal of $CaCO_3$ or by replacement.

In all probability both processes have taken place and in most cases it is difficult to say which method has prevailed.

A disputed point concerns the time when and place where the leaching of the $CaCO_3$, or its replacement, occurred. Geologists seem to favor the belief in the change having been effected mainly in the ocean bottom when the limestone existed in the unconsolidated condition as ooze or loose shells. Magnesium exists in ocean water in much larger quantity than does calcium, averaging about 3.72 per cent of the salts contained in solution. By the action of decaying organic matter in warm, shallow waters the solution of $CaCO_3$ and also the substitution of magnesium for calcium are believed to have gone forward most rapidly. The effect of decaying organisms is shown by the selective replacement of fossil shells by dolomite in some limestones in which the matrix remains calcite.

In most cases the action of sea water probably ceased rather uniformly at shallow depths in the deposits and the variation in composition in individual beds is not marked. In places, however, one finds a bed changing in a short distance laterally from a dolomite to a low magnesian limestone. Conditions of this kind are interpreted to mean a continuation of the alteration, after the deposition of overlying deposits, due to some physical characters that gave ready access to the magnesian waters in certain places but not everywhere.

In some limestone quarries of this State dolomitization has taken place on a considerable scale and the rock varies materially in composition even though the beds are continuous.

In the shells of organisms magnesium and calcium carbonate seem to exist as separate molecules and there is still no direct evidence of the way in which the double molecule of dolomite is formed although theoretical explanations have been offered.

We accept the view of dolomitization at the time of formation of the limestone as the most plausible explanation for most of our magnesian limestone but are still without definite evidence to account for the extreme and sharp variations that prevail in the alternating strata of the Cambrian and Ordovician rocks of this State, as described on later pages. We can only suggest changes in the density of the ocean water, changes in temperature and pressure, and changes in the character of the organisms forming the deposits as the more probable causes. As oolites, cross bedding, intraformational conglomerate, ripple marks, sun cracks, and numerous shale laminae are characteristic of these strata we are warranted in concluding that the water was shallow over wide expanses, thus facilitating rapid and frequent changes, such as suggested.

We cannot escape the conviction that dolomitization may have occurred in later periods as well, even after consolidation of the limestones and their uplift from beneath the ocean, owing to ground water circulating through the rocks. These effects, however, are subordinate to the ones described above. Limestones have been found in which the magnesian content increases with proximity to shattered zones and cracks or joints through which the ground water passes readily. In these cases the cause has been dolomitic enrichment due to the removal of the more soluble calcite.

In general the circulating ground water accomplishes little in the replacement of limestone by dolomite. Yet it must be remembered that dolomite is a gangue mineral in certain ore deposits, proving that it is carried in solution by ground water and there is thus the possibility of local replacement of $CaCO_3$ by $MgCO_3$ by this agency.

ORIGIN OF MARBLE.

Marble is a metamorphic, compact variety of limestone or dolomite and differs from the original rock only in the granular and more coarsely crystalline character of the particles composing it. There is no distinct line of separation between limestone and marble but in general those calcareous stones that will take a high polish are called marble. This character depends upon the compactness of the stone and the crystallinity of the particles. The separate grains which break along cleavage planes may vary from microscopic size to crystals several inches in diameter. Marble may be designated as calcareous, magnesian or dolomitic depending upon the amount of magnesium present.

By experiment it has been found that pressure and heat in the presence of moisture are the effective metamorphic agents in the formation of marble. The intrusion of limestone beds by molten igneous material will change the limestone to marble for a short distance from the contact. This is called "contact metamorphism" and is of local importance only. The extensive areas of marble are due to pressure and heat caused by folding or compression of the earth's strata. This is designated "regional metamorphism". In general those strata that have been subjected to the greatest stresses are most coarsely crystalline, although the composition of the rock, the thickness of overlying rock. the quantity of moisture present, and possibly other factors may have their effect. This is shown to good advantage in the limestones and marbles of this State where the pre-Cambrian calcareous strata have undergone intense deformation numerous times and have been converted into coarsely crystalline marbles. The Cambrian and Ordovician limestones have twice been folded and faulted and in many places have been changed into fine-grained marbles, whereas the later limestones of Carboniferous age have been subjected to a single period of mountain building by compression and are in few places sufficiently crystalline to justify their designation as marble.

As described under the topic of "Chemical and Mineralogical Composition", marble formed from impure limestone contains a wide variety of minerals, the most common of which are graphite, tremolite and garnet.

WEATHERING OF LIMESTONE.

Limestone is worn away by corrosion, by frost action, and in various other ways like all rocks, but, in addition, by solution which in the case of most rocks is of little consequence. Under certain conditions limestone beds are disintegrated by physical means and we have in the Triassic of Pennsylvania occasional beds of conglomerate containing pebbles or cobbles of limestone derived from nearby Paleozoic strata. However, the removal of limestone is primarily by solution. Pure water will dissolve limestone slowly but with carbon dioxide or humus acids derived from decaying organic matter the solution becomes active. Magnesium limestones are less soluble but even they are much more readily dissolved than most rocks of the earth's crust.

The solution of the limestone is mainly accomplished by ground waters that, flowing through cracks in the rocks, dissolve the adjacent material. Caves result from this action wherever thick limestones outcrop or come near the surface. In the limestone valleys of Pennsylvania numerous large caves have been discovered and innumerable sink holes, due to the collapse of the cave roofs, can be found. So abundant are these sink holes in some places that most of the rain water sinks underground directly and helps to form subterranean streams. In the great limestone areas of the State, surface streams are rare and the rocks are so cavernous that the residents of some towns and cities dispose of their sewage by dumping it into these cavities. Holes are dug to locate these caves and in most cases the first attempt is successful. In some instances the passage ways later become clogged by the sewage and new holes must be opened into other passages, but generally the caverns are sufficiently large and open so that they serve their purpose satisfactorily year after year.

The problem of securing ample supplies of good well water in limestone regions has become a serious one in many sections. The limestones themselves are relatively impervious so that little water passes through them and the solution channels permit most of the ground water to collect in definite subterranean streams. Accordingly when a well encounters one of these major streams an unfailing and almost unlimited supply is obtained. In some cases these streams emerge at the surface, as illustrated by Boiling Springs in Cumberland County where a fair-sized creek is formed by water from these springs. If a well fails to strike one of these streams it may furnish practically no water regardless of its depth. There are extensive areas in the great limestone areas of Pennsylvania where the farmers depend entirely upon cistern water for their domestic supply.

The quality of the water obtained from limestone is a matter of considerable concern. Almost invariably it is "hard", that is heavily charged with $CaCO_3$, rendering it highly undesirable for boiler purposes and unsatisfactory for most uses. It is also likely to be contaminated on account of the open character of the channels and the ease with which surface water passes under ground with a minimum of filtration.

CHARACTERISTICS OF LIMESTONE REGIONS.

As the result of solution by water the areas underlain by thick beds of limestone have been reduced to lower levels, leaving the less soluble rocks, particularly the quartzose and igneous or metamorphic non-calcareous rocks to form the ridges. This is true regardless of the structure of the rocks. Some striking examples of limestones valleys are the Nittany Valley in Centre County and the Nippenose Valley in Lycoming County, where the rocks have been folded upwards, forming anticlines, but with the center of the folds now forming the valleys. This is due to erosion having worn through the siliceous rocks that once capped the highest portions of the folds and then opening up valleys of solution in the underlying limestones. All valleys of Pennsylvania are not floored with limestone, although most of our valleys lying east and southeast of the Allegheny Front are. It can be positively stated that no important ridges in the State are composed of limestone. In regions that have been uplifted by folding in more recent times than the mountain building of the Appalachians or where solution is less active, limestone ridges do occur, as in some portions of the Rockies and the Alps, but never in old regions of humid climates.

The soils of limestone areas are apt to be thin unless winds, streams, or glaciers have brought foreign debris into the regions, as is true in some of the limestone valleys of the State. The soil resulting from the decomposition of limestone consists of the insoluble impurities left as a residuum by the removal of the carbonates. The purer the limestone, the smaller the amount of soil formed by its decomposition. Also in time, a large portion of the residual soil finds its way into the streams and is carried off by heavy rains even in fairly level areas containing numerous sink holes. Consequently in the comparatively flat-floored limestone valleys the outcrops of rocks may be so numerous and the soil so thin as to seriously interfere with cultivation.

Limestone soils are highly colored by the oxides of iron that were present in the original limestones in smaller amounts either in that form, or as carbonates or sulphides. In the latter case these compounds have oxidized during the decomposition of the rocks. The soils are fine-grained, due to the fine state of division of the rock impurities and when wet are unusually plastic. They are well adapted to the growth of corn, grass and small grain and constitute the most important agricultural soils of the State. They are also suitable for the manufacture of brick and tile and have been utilized for these purposes in many parts of Pennsylvania.

METALLIC MINERAL DEPOSITS ASSOCIATED WITH LIMESTONES.

Limestone is of extremely great importance in many sections of the world because of its effect in the formation of certain metallic ore bodies. Lead and zinc ores are more commonly associated with limestone than with any other kind of rock and ores of iron and manganese are common to it.

In Pennsylvania, zinc ores were formerly extensively worked at Friedensville, Lehigh County, where they occur as replacements of, and fracture fillings in, the Ordovician magnesian limestone. At Landisville, Lancaster County, and Birmingham, Blair County, lead and zinc ores have also been worked in the Paleozoic limestones. There are a number of other places in the State where lead and zinc minerals have been found in limestone but not in sufficient quantity to justify the opening of mines.

Residual limonite ores have been mined in hundreds of the limestone valleys of the State. In some cases the ore bodies covered extensive areas, extended to depths of 100 to 200 feet, and contained tens of thousands of tons of ore. The iron industry of Pennsylvania was mainly dependent upon this class of ore for many years but its importance gradually declined as improved transportation facilities permitted the importation of higher grade Lake Superior and Adirondack ores. For several years past all these limonite mines have been idle. Ochre was found in association with the limonite iron ore and some of these deposits are still operated at intervals by paint companies.

The limonite and ocher in the limestones owe their origin to the action of ground water that removed the limestone and concentrated the iron materials originally disseminated throughout the strata. The concentration was most pronounced in shattered zones of the limestone where there was free circulation of the ground water.

The oxidized ores of manganese and iron are commonly found in association. In this State manganese ores are of little consequence but manganiferous limonite ores in the past were worked in many places. Umber, which is manganiferous ocher, has been mined in several localities, even within recent years.

The Cornwall iron mine in Lebanon County, most important iron mine ever developed in Pennsylvania, owes its origin to the presence of a great thickness of Paleozoic limestone. A dike of igneous rock brought up the iron-bearing solutions or else prepared the way for the solutions which have replaced the limestone by magnetite for a considerable distance from the contact. The ore body thus formed has already yielded more than 25,000,000 tons of ore. The ore also contains appreciable amounts of copper, cobalt, silver, and gold. In the past other iron ore bodies of a similar character have been worked in the State.

A stratum of siderite (iron carbonate) ore ranging in thickness up to 3 or 4 feet commonly overlies the Vanport limestone in western Pennsylvania. It was formerly mined on a small scale in several localities, especially in Armstrong, Butler, and Lawrence counties. This ore has been formed by the replacement of limestone by descending ground waters carrying iron in solution. The iron ore contains fossils just as does the high grade limestone beneath it.

Ores of copper formed by replacement of limestone are of great importance in the Southwest but of no consequence in Pennsylvania, although traces of copper have been noted in some of our limestones.

USES OF LIMESTONE (including Dolomite).

Ordinarily the uses of limestone, dolomite, and lime are discussed separately but such treatment involves considerable repetition inasmuch as these different substances may be used interchangeably or in various combinations in numerous cases. The variety of uses for limestone and limestone products is so great that it is inadvisable to attempt a complete description in this place, and only the principal uses will be described. As there are many different opinions at the present time in regard to the comparative value of these materials for various uses, one can only present the different points of view and wait for the accumulation of more data before reaching a final conclusion.

Building and decorative purposes.

Limestone and marble have been used more extensively for building purposes than any other class of stones. Although less durable than granite they are more attractive for many purposes on account of the light color. However, their extensive use is due to their wide distribution in almost all countries and to the ease with which they can be quarried and dressed.

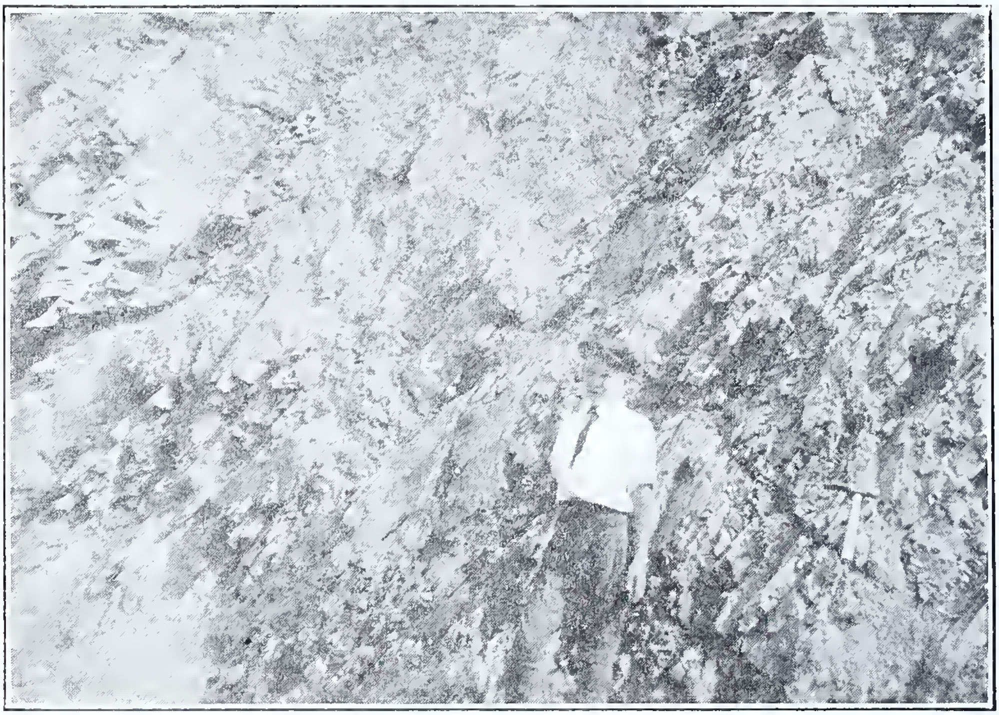
The chemical composition of the calcareous stones used in structures is of no particular importance unless there be present some objectionable materials such as pyrite or other easily decomposable minerals or hard minerals, such as quartz, that would interfere with sawing and dressing the blocks. The important qualifications are desirable color, evenly bedded, regular strata of the desired thickness, and joint planes regularly spaced for the extracting of fair-sized blocks. In some sections the limestone is worthless for structural purposes on account of the numerous joints, gnarly and uneven character of the rock, and the thin beds. Plate I A illustrates limestone shattered by compression.

The limestones of the State have been used extensively for walls of houses, for sills and lintels in buildings mainly constructed of other materials, for curbing, pavements, etc. Marble is used generally for interior decorative work, for monuments, door steps, etc., and also is used for public buildings and residences. A number of fine buildings in the State have been constructed of Pennsylvania marble.

Crushed and pulverized stone.

The use of crushed limestone for road metal, ballast, and concrete and of pulverized limestone as a filler and in agriculture is continually increasing. The use of pulverized stone for soil conditioning will be discussed on a later page under the head of "Agriculture."

PLATE I.



A. Badly shattered Cambro-Ordovician limestone in quarry near Shremer, Lancaster County.

B. Burning agricultural lime in open heap.

Road metal.—Limestone is more extensively used for road metal than any other kind of stone. Although less durable than trap rock or granite it is quarried and crushed at less cost and in addition the powder formed by attrition possesses excellent binding qualities.

Standardized laboratory tests are made to determine certain physical properties that affect the value of the stone. The tests made by the State Highway Department are the following: (1) specific gravity, (2) weight per cubic foot in pounds, (3) absorption per cubic foot in pounds, (4) per cent of wear, (5) French coefficient of wear, and (6) crushing strength in pounds per square inch. The U. S. Bureau of Public Roads also tests for hardness and toughness. Most of the tests have been standardized by the American Society for Testing Materials.

In the determination of specific gravity a fragment of rock of approximately 10 grams is dried for several hours to a constant weight. It is first weighed in air and then in water. The specific gravity is the product of the weight in air divided by the difference between the weight in air and the weight in water. The specific gravity of limestone and dolomite averages about 2.70, seldom lower than 2.60 nor higher than 2.85.

The weight per cubic foot is obtained by multiplying the weight of a cubic foot of water (62.5 lbs.) by the specific gravity of the stone. Limestone averages about 168 pounds per cubic foot and dolomite 170 pounds. These figures are useful in estimating the weight of a certain volume of stone. If the stone is crushed, it is customary to make a 50 per cent allowance for the spaces between the particles.

The absorption is determined by weighing a dried specimen of rock before and after immersing in water for 96 hours. The difference in weight represents the amount of water absorbed. The ability of limestones to absorb moisture varies greatly, ranging from a few hundredths of 1 per cent to more than 13 per cent. The absorption is usually expressed in pounds per cubic foot. This test is of value in determining the durability of limestones exposed to freezing action. A porous rock may be badly disintegrated by the frosts of a single winter in such a climate as that of Pennsylvania where there are numerous thawings and freezings during the winter months.

The fragments of stone used in road building wear by abrasion and it has been found necessary to determine the rate of wear. This is done by the standardized Deval abrasion test. The sample to be tested consists of 5 kilograms (about 11 pounds) of freshly broken stone about 2 to 2½ inches in size. The number of pieces should be about 50, certainly no less than 40 nor more than 60. After thorough drying, the rock is put into a cylinder mounted on an axis inclined 30° to the cylinder. The cylinder is revolved 10,000 times at the rate of 30 revolutions per minute, each revolution throwing the material from end to end twice. The abrasion is accomplished by particle rubbing against particle and by striking against the sides and ends of the cylinder. The fine material is screened through a one-sixteenth inch mesh screen. This is weighed to determine the per cent of wear. The French coefficient of wear is determined by dividing 40 by the per cent of wear. The average per cent of wear of limestones is about 5 and the average French coefficient of wear is about 8.

The crushing strength of road metal, although not often determined, is measured by pressure required to crush a cylinder of stone 2 inches in diameter and 2 inches long. The average of two or more determinations is expressed in pounds per square inch. Limestone and dolomite of the ordinary type crush at pressures of 18,000 to 19,000 pounds per square inch but some siliceous varieties have a crushing strength of more than 30,000 pounds. Porous limestone and marble crush at pressures of 8,000 to 12,000 pounds and are therefore not acceptable for road use.

The hardness of a specimen is determined by drilling from it a cylinder rock core 25 millimeters in diameter and then subjecting the end of the core to the abrasive action of standard quartz sand between 30 and 40 mesh in size on a revolving steel disk under a constant pressure of 1,250 grams. After 1,000 revolutions the loss of weight is determined. The coefficient of hardness is 20 minus one-third of the weight loss. Limestone and dolomite have an average hardness of about 15 and marble about 14.

In the toughness test, a steel plunger with a spherical lower end resting on a cylinder of stone 25 millimeters (1 inch) long and 25 millimeters in diameter is subjected to the impact of a hammer weighing 2 kilograms (4.4 pounds). The height of the drop of the hammer is increased 1 centimeter (0.39 inch) after each blow. The height of blow in centimeters at which the specimen breaks is called the toughness. The average toughness is about 7 for limestone and 5 for marble.

Another test, called the cementing value or binding power test, is sometimes employed. In this a sample weighing 500 grams (1.1 pounds) is crushed to pea size and then finely ground in a ball mill to the consistency of a thick dough. Cylindrical briquettes 25 millimeters (1 inch) in diameter are molded from the rock paste and thoroughly dried. A plunger on the end of the specimen is repeatedly struck by a 1 kilogram (2.2 pounds) hammer falling a distance of 1 centimeter (0.39 inch). The number of blows required to break the specimen is called the cementing value of the stone. Limestone, dolomite, and marble have high values in comparison with other kinds of rock. Over 75 per cent give values exceeding 25 and a few more than 500. This is one of the important reasons for the widespread use of limestone for water-bound macadam roads.

Ballast.—Crushed limestone has been widely used for railroad ballast in the past but has been decreasing in favor in recent years. One reason is that the heavy rolling stock demands a rock of high crushing strength and limestone in this respect does not compare favorably with many of the siliceous rocks. Another reason given is that the binding quality is too high. The expense of removing limestone ballast to replace ties is high as compared with other varieties of rock. This binding power, on the other hand, increases the value of limestone as ballast in places where it need not be disturbed.

Concrete.—Due to the angular character of the individual fragments of crushed limestone it has been extensively employed for all kinds of concrete work, although the specifications vary in different cases. A large percentage of dust is objectionable.

Filler.—In recent years there has been an increasing demand for inert mineral substances as fillers in the manufacture of various products. White clay, barite, mica, talc, silica, slate, limestone, and occasionally graphite and ocher are used. In every case the materials are finely ground and in almost every instance used in the raw condition. Pulverized limestone or marble, commonly called whiting, (although correctly whiting is ground chalk) are probably used in larger quantities than any of the other fillers. For this purpose waste materials are commonly employed, especially waste marble, but the increasing demand and high transportation rates are resulting in the production of this material in other sections.

In every case it is necessary to grind the material very fine in either roller, tube or ball mills. Some specifications call for 98 or 99 per cent fine enough to pass through 200 mesh and others 300 mesh. The finest material is obtained by water flotation, or air separation.

Probably the most extensive use of limestone filler is in asphalt paving mixtures where its presence toughens the mix and renders it less susceptible to temperature changes. It is also "used in rubber, paint, a few grades of paper, linoleum, oilcloth, shoe polish, putty, tooth powder, roofing and artificial stone. For use in rubber, linoleum and paint the alkalinity should be very low. Freedom from grit is required for nearly all uses. A pure white color is essential for use in paint, shoe polish, and similar products. Low oil absorption is of greatest importance in the paint and linoleum industries. There are many grades of whiting, ranging from the amorphous material produced from true chalk to the highly crystalline material from marble. Different whitings possess different physical properties, often when quite similar in chemical composition, fineness, and appearance. Such differences are often difficult to understand. For example, of two whitings of similar chemical composition, grain size, and general appearance, one will make good putty while the other may not."[12] The Bureau of Mines is carrying on additional research work to try to determine the best type of mineral fillers for each particular purpose.

Flux.

Limestone is essential as a fluxing material in the manufacture of iron and steel. Between one-third and one-half of all the limestone produced in the United States is used in this way. The purpose of the limestone is to make a fusible slag of the impurities of the iron ore, mainly silica and alumina, and the ash of the coke. Ordinarily about half a ton of limestone is used for a ton of pig iron.

The suitability of a limestone for use as flux depends almost entirely on its chemical composition although the physical condition is of importance. For example, there must not be much dust and this fact eliminates marl from furnace use.

Limestone for flux should be low in silica and alumina, the lower the better. Since the object of the limestone is to remove these impurities the material is obviously less efficient if it contain much of either of these two substances. However, they are both present in practically all limestone and the amount that will be tolerated depends upon availability and cost of the stone. Whereas one company favorably located with respect to good fluxing limestone will only accept stone containing less than 3 or 4 per cent of alumina and silica, another company, less advantageously situated may find it cheaper to use stone with double the amount of impurities. In general purer stone is required for the open hearth process than for the blast furnace.

"Referring to limestone and dolomite as blast furnace materials, there is a difference of opinion among furnace men to their relative value as fluxes. Some hold that limestone is the better, while others maintain that dolomite gives as good, if not better results, their opinion usually being influenced by their training and by the extent of their experience with these materials. The presence of magnesium in limestone in small amounts has little effect, but as the content increases, it may lower the fusion point of the resultant slag by the formation of double salts. A high percentage (over 3 per cent) of magnesia in blast furnace slag renders it undesirable for cement, but for concrete, ballast, etc., it is desirable as it makes the slag harder. Aside from this objection, not one of much weight, the factor that governs the choice between limestone and dolomite is the cost per ton of available base".[13]

Sulphur and phosphorus are undesirable in fluxing limestone although rarely are they present in sufficient quantity to demand consideration.

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[12] Weigel, W. M., Non-metallic mineral filler industry: Trans. Amer. Inst. Min. and Met. Eng., Vol. 68, pp. 587-603, 1923.

[13] Camp, J. M. and Francis, C. B., The making, shaping and treating of steel: Second Edition, p. 118, Pittsburgh, 1920.

The limestones and dolomites of Pennsylvania have long been used as flux by the iron and steel industries of the State and numerous analyses of such materials are given on later pages of this report.

Cement.

A continually increasing use for limestone is in the manufacture of cement. In this industry Pennsylvania exceeds all other States. There are three kinds of cement, all of which require the use of lime or limestone,—natural, slag (puzzolan or puzzuolan) and Portland cement.

Natural cement.—Natural cement, also called Rosendale or Roman cement, is made by burning an argillaceous limestone at temperatures of 1000° to 1100° C. The raw material is of variable composition and in the burning seldom reaches the clinkering (fusing) stage. Nevertheless important chemical action takes place and calcium aluminum silicates are formed. The burning process is similar to the burning of lime. The resulting product is ground fine. It differs from Portland cement in that it sets more rapidly but possesses less strength. It is cheaper on account of less attention being given to the chemical composition of the material and less care in the burning.

Until 1900 the production of natural cement exceeded that of Portland cement but since that year there has been an enormous increase in the production of the latter and a slow but steady decrease in the former until now the production of natural and puzzolan cement combined in the United States in less than one per cent of the entire cement production.

Slag or puzzolan cement.—Puzzolan cement was originally made at Pozzuolia near Naples, Italy, by the intimate mixture of volcanic lava and slaked lime. It has also been made in other sections of the world. The similarity of basic slags of the blast furnace and lavas suggested the use of slag in the same way and at one time the slag cement industry gave promise of reaching considerable proportions and to successfully competing with Portland cement. This condition has not been realized and production has declined in recent years. In some cases slag cement will pass all the necessary tests for Portland cement but usually it possesses less strength and sets more slowly.

Few processes are involved in the manufacture of puzzolan or slag cement as it is merely an intimate mechanical mixture of slaked lime and slag, ground fine before, during or after the mixing of the two ingredients.

Slag or puzzolan cement must not be confused with true Portland cement in which blast furnace slag and limestone are mixed in the proper proportions chemically and burned in the ordinary way as described below.

Portland cement.—The principal cement of the world is named "Portland" because of its resemblance after hardening to the Portland limestone of England, a stone extensively quarried and widely used. Pennsylvania has been the principal producing State since the beginning of the industry in this country and in recent years probably half of the limestone quarried in the State has been used in this way.

In the manufacture of Portland cement, limestone of various kinds is used either alone or admixed with other materials. Argillaceous limestone in the Lehigh district of Lehigh and Northampton counties has the correct chemical composition for the manufacture of Portland cement, but elsewhere in Pennsylvania it is necessary to mix other material with the limestone to obtain the proper proportions of the requisite ingredients. The manufacturers attempt to secure a uniform composition of about 75 per cent $CaCO_3$, 12 to 15 per cent SiO_2, and the balance Al_2O_3 and Fe_2O_3. There is almost always some $MgCO_3$ present but this is undesirable and should not exceed 5 or 6 per cent. For this reason dolomite and high magnesian limestone are unsuited for Portland cement manufacture but practically all other kinds of limestone, including calcareous marls, shells, etc., can be utilized if mixed with proper ingredients to secure the necessary elements. Argillaceous limestone is most suitable as it more nearly approaches the proper composition. Alkalies and sulphates are objectionable but rarely are they present in sufficient quantities to warrant consideration.

If the limestone is deficient in alumina and silica it is a common practice to add clay or shale, although some companies use blast furnace slag with satisfactory results. If the limestone has a $CaCO_3$ content less than 75 per cent, it is necessary to add a certain amount of higher grade limestone and in various regions high-calcium limestone is quarried for mixture with argillaceous limestone, shale or clay.

The process of manufacture is simple although a wide variety of machinery is used by the various companies. Crushing and fine grinding in ball or tube mills, burning in rotary kilns at temperatures of 1400° to 1500° C (2500° to 2700° F) to produce clinkers, and later fine grinding of the clinker to which a small amount of gypsum has been added to retard the setting, constitute the process.

USES OF DOLOMITE.

Furnace lining.—Considerable dolomite is used for lining open hearth furnaces. Although inferior to magnesite for this purpose it is widely used nevertheless on account of its lower cost. The more nearly the stone approaches the composition of magnesite, the more desirable it is. Considerable dolomitic stone with no more than 35 per cent $MgCO_3$ has been used although all the steel companies desire a $MgCO_3$ content of 40 per cent or more. The silica content should be less than 2 per cent and alumina equally low.

In recent years there has been considerable demand for low-silica dolomite and several deposits have been found in this State. However, a large part of the stone used in the steel plants of Pennsylvania comes from outside the State.

Manufacture of magnesia.—The extraction of magnesia from dolomite has become a rather important industry in this State.

For this purpose a stone with from 43 to 48 per cent $MgCO_3$ is used. One hundred pounds, in blocks from 8 to 12 inches in diameter (one-man size), mixed with 11 pounds of coke, is calcined in a closed kiln. The CO_2 is drawn into a gas compressor. The burned product is slaked and ground in a pebble mill and then mixed with an excess of water. Into the mixture, CO_2, obtained from the kiln, is forced under pressure. This causes the magnesium hydroxide to pass into solution, leaving $CaCo_3$ mainly with the impurities derived from the stone and the coke as a fine precipitate. By filtering in filter presses the magnesium solution is separated from the precipitate.

The precipitated $CaCo_3$ is suitable for whiting, cement, paint, fertilizer, etc., but due to the expense of drying it is in most cases discarded. In one plant this residue contains from 92 to 96 per cent $CaCO_3$. The solution from the filter presses carrying a little more than 2 per cent magnesium bicarbonate is boiled in closed upright boilers, causing the precipitation of hydrated basic carbonate of magnesia. The CO_2 driven off is drawn back into the gas compressors, and the magnesium carbonate and water conducted into a gravity filter. At this stage there is a division of the product depending upon the use to which the material is to be put. It may be dried and moulded and put on the market as the hydrated basic carbonate of magnesium or magnesium alba for pharmaceutical uses, for the rubber trade or as a face powder or toilet article. It may be calcined to form MgO and sold for pharmaceutical purposes or for the rubber and chemical industries. Most of it, however, while still containing considerable water, is thoroughly mixed with shredded asbestos in the proportion of 85 per cent magnesium carbonate to 15 per cent asbestos, and moulded into bricks or forms for covering steam pipes, etc. It serves as an excellent heat insulator due to the numerous tiny air cavities present between the grains of the magnesium carbonate. The asbestos fibres are also poor heat conductors although their principal use is as a binder to increase the strength of the forms.

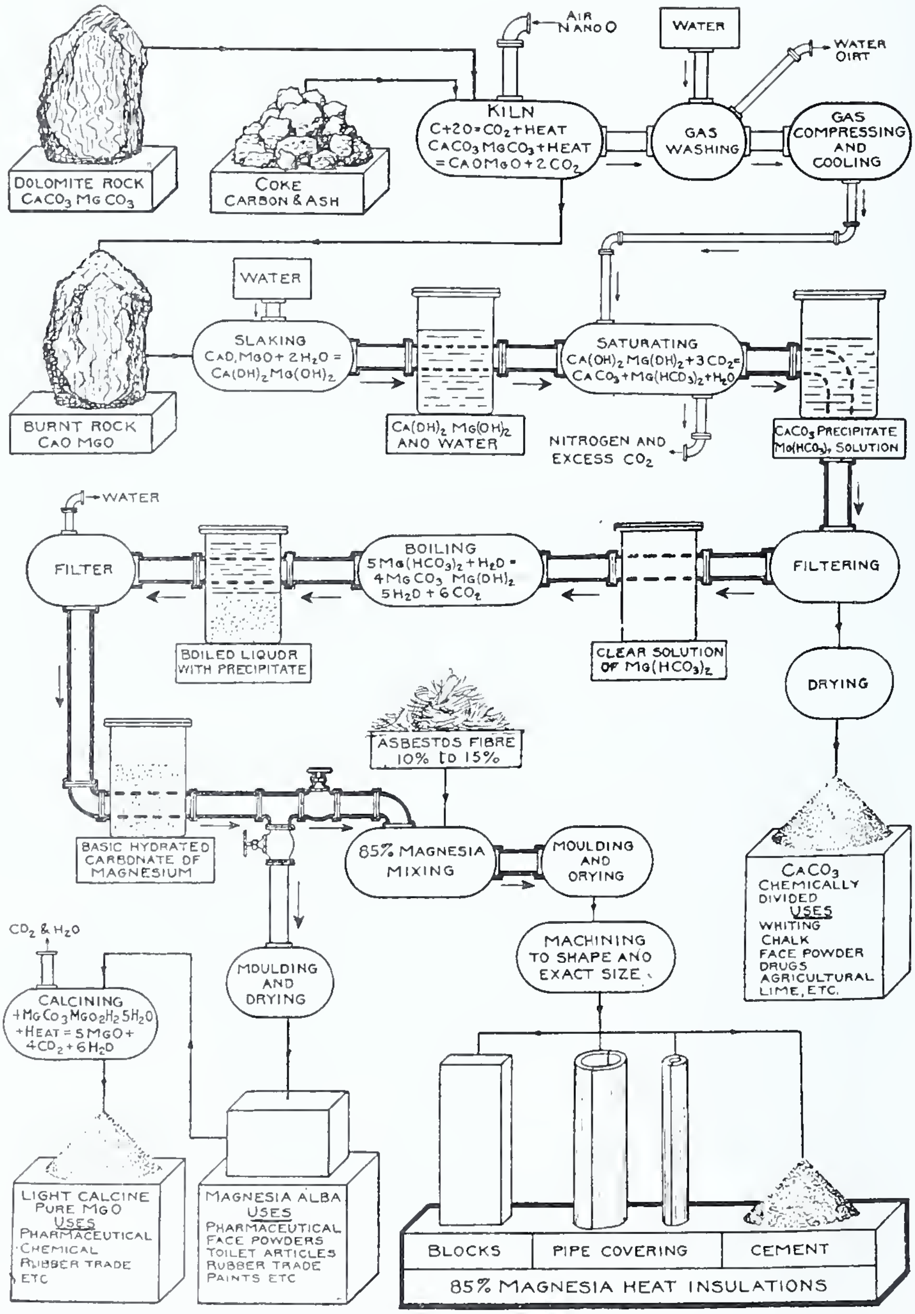
DOLOMITE ROCK $CaCO_3 MgCO_3$
COKE CARBON & ASH
AIR N AND O
KILN
$C+2O=CO_2+HEAT$
$CaCO_3MgCO_3+HEAT = CaOMgO+2CO_2$
WATER
GAS WASHING
WATER DIRT
GAS COMPRESSING AND COOLING
BURNT ROCK $CaO MgO$
WATER
SLAKING
$CaO,MgO+2H_2O = Ca(OH)_2Mg(OH)_2$
$Ca(OH)_2 Mg(OH)_2$ AND WATER
SATURATING
$Ca(OH)_2Mg(OH)_2+3CO_2 = CaCO_3+Mg(HCO_3)_2+H_2O$
NITROGEN AND EXCESS CO_2
$CaCO_3$ PRECIPITATE $Mg(HCO_3)_2$ SOLUTION
WATER
FILTER
BOILED LIQUOR WITH PRECIPITATE
BOILING
$5Mg(HCO_3)_2+H_2O = 4MgCO_3 Mg(OH)_2 5H_2O+6CO_2$
CLEAR SOLUTION OF $Mg(HCO_3)_2$
FILTERING
DRYING
ASBESTOS FIBRE 10% TO 15%
BASIC HYDRATED CARBONATE OF MAGNESIUM
85% MAGNESIA MIXING
MOULDING AND DRYING
$CaCO_3$ CHEMICALLY DIVIDED
USES
WHITING
CHALK
FACE POWDER
DRUGS
AGRICULTURAL LIME, ETC.
CO_2 & H_2O
CALCINING
$4MgCO_3MgO_2H_25H_2O + HEAT = 5MgO+4CO_2+6H_2O$
MOULDING AND DRYING
MACHINING TO SHAPE AND EXACT SIZE
LIGHT CALCINE PURE MgO
USES
PHARMACEUTICAL
CHEMICAL
RUBBER TRADE
ETC
MAGNESIA ALBA
USES
PHARMACEUTICAL
FACE POWDERS
TOILET ARTICLES
RUBBER TRADE
PAINTS ETC
BLOCKS
PIPE COVERING
CEMENT
85% MAGNESIA HEAT INSULATIONS

Figure 1. Flow chart illustrating manufacture of magnesia. The darkened lines show the actual process involved; the lighter lines, by processes.

A flow sheet, prepared by the Magnesia Association of America, showing the various chemical changes involved in the process is given in the accompanying figure.

USES OF LIMESTONE AND LIME.

Agriculture.—The value of lime and limestone to the agricultural industry has long been recognized and for centuries farmers have fertilized the soil by the application of limestone, chalk, oyster and clam shells, and calcareous marl, either in the raw or in the calcined condition. Such material produces the following effects: (a) It will neutralize active acid. (b) It creates a condition in the soil favorable for the growth of many valuable crops. (*c*) Its presence favors the growth of many of the legumes and promotes the use of the nitrogen of the air by those plants. (d) It improves the type of decay of organic matter in the soil with the formation of humus. (e) It supplies nutrients in the form of calcium and magnesium for the use of plants. (f) It may improve the tilth of the soil. (g) It improves the sanitary condition of the soil.[14]

In an elaborate chart issued by the National Lime Association a number of the other specific cases are given showing the agricultural value of lime in crop production and protection, animal growth and protection, and the protection and preservation of animal products.

Recent investigations have shown that most plants require both calcium and magnesium, which means that magnesian or dolomitic limestone is preferable as fertilizer to the pure calcareous variety. The calcium is built up as an essential constituent of the stems, leaves and roots whereas the magnesium is stored up finally, mainly in the stems. Magnesium also constitutes an important part of chlorophyll, the green coloring matter of plants. The relative amounts of calcium and magnesium best suited for fertilizing use has not been definitely determined but probably depends upon the kinds of plants. The neutralizing ability of dolomitic limestone is greater than that of pure calcium limestone but the high-magnesian stone will produce only a faint degree of soil alkalinity, probably explained by the greater tendency of the magnesium to enter into chemical combination with some of the silicates of the soil.

The improvement of the tilth, or friable condition of the soil, is brought about by the addition of quick lime which tends to flocculate the soil particles and render a heavy clayey soil much more porous and granular and a sandy soil less porous. A clay soil will drain much better if lime is added, and the roots of the plants can more easily obtain the necessary nourishment.

With the exception of the last mentioned uses all of the benefits of soil fertilization can be obtained by the addition of ground quicklime, hydrated lime, air-slacked lime, or ground limestone. There is great divergence of opinion in regard to the relative merits of the different materials but the principal factor is undoubtedly the cost per unit of calcium oxide. Viewed in this manner, 500 pounds of quicklime, the amount commonly specified for one acre, is the equivalent of 950 pounds of hydrated lime or 1250 pounds of air-slaked lime or ground limestone. The action of the ground limestone is slower and the effect will extend over a longer period of years than if lime is used. Oyster shells and calcareous marl have long been used in the soils, but the use of pulverized limestone is a rather recent application and the annual production is rapidly increasing. There is considerable difference of opinion in regard to the most effective state of fineness of ground limestone. In some cases a product that will pass through a 100 mesh screen is guaranteed but more general practice calls for 15 to 18 per cent from 10 to 50 mesh size, 10 to 12 per cent between 50 and 100 mesh size, and 70 to 75 per cent finer than 100 mesh. Naturally the coarser particles may remain in the soil several years before they are entirely decomposed.

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[14] Fippin, E. O., The use of lime on the soil: N. Y. State College of Agri. at Cornell Univ. Lesson 148, Ithaca, 1919.

Glass manufacture.—Calcium oxide is a necessary constituent in the manufacture of most glass. It is commonly introduced in the form of ground limestone but in some plants quicklime is used and in others hydrated lime. Cost, availability, and present practice are the principal determining factors although the kind of glass manufactured may require a particular form of calcium oxide. There is also considerable variation in the permissible impurities. High magnesium material may be used, and in some kinds of optical glass, is desirable. The presence of magnesia renders the mixture more difficult to melt. The silica content should be less than 4 per cent for the best glass but may run as high as 17 per cent for some varieties. Alumina should be less than 3 per cent, except for some glass in which 5 per cent is allowed. Sulphuric and phosphoric anhydrides should be less than 1 per cent. Iron is objectionable because of its coloring properties. For the best glass no more than 0.2 per cent is permissible, but for the poorer qualities 0.8 per cent is allowed.

Ceramic industry.—Limestone and lime are used as fluxes in the manufacture of pottery and porcelain. Ground limestone is mainly employed, principally because of the lesser cost, but lime is necessary in some cases. Magnesian material is desirable as the points of vitrification and fusion are farther apart when magnesia is present although high calcium limestone and lime are also used. For glazes a low magnesian content is better. Due to the relatively small amount of calcareous matter required the impurities present can usually be ignored.

Paints.—Ground limestone, chalk, hydrated and air-slaked lime are used in the manufacture of paint. The chief essentials are extreme fineness of the product and desirable color. The presence of magnesia seems to improve the spreading qualities of the paint.

Slaked lime is the pigment of whitewash that in earlier times was more extensively used as a paint both on interior and exterior surfaces than at present. It is also mixed with other ingredients in the manufacture of more elaborate paints.

Calcium carbonate as natural chalk, pulverized limestone or marble, or the chemically precipitated variety is used in several kinds of paint as an "extender" or harmless adulterant to increase the volume of the paint. In this case cheapness determines its use. It may have a positive value as do several of the so-called "extenders" but this has not been proved.

Mortar, plaster, stucco, and concrete.—At one time practically all the lime made was used in the preparation of mortar and plaster and this use still accounts for about 28 per cent of the total annual production of the country. Ordinary mortar is a mixture of slaked lime, water, and sand. Cement, hair, plaster-of-Paris and other materials are frequently added. The mortar hardens by the evaporation of the water and the slow gradual change of the calcium hydroxide into calcium carbonate by extraction of carbon dioxide from the air. Both magnesian and non-magnesian limes are used, each of which possesses certain advantages. High calcium lime when mixed with water will make more putty and will hold more sand, hence more mortar can be formed from it. On the other hand the shrinkage is greater and there is a greater tendency to crack. There is also a tendency for masons to overload the high calcium lime with sand. Mortar made with high magnesian lime is considerably stronger than high calcium mortar and can be spread more evenly, hence is generally preferred by masons. It is also whiter.

The sale of hydrated lime for mortar and plaster is steadily increasing as there is a tendency for lime to "burn" when insufficient water is added and the mixture is imperfectly stirred. Just what happens when the "burning" takes place is not well understood but the "burnt" lime is practically useless and when used in mortar is apt to break away, leaving small pits.

In most cases the exact color of mortar is a matter of indifference but plastering mixtures must conform to color specifications, usually the whiter the more acceptable. Lime is used in stucco and concrete to make these mixtures less permeable to water.

Sand-lime brick.—Considerable lime is used in the manufacture of sand-lime brick, an industry that has shown remarkable development since 1901 when the first plant in this country began operations at Michigan City, Indiana. In 1920, seventeen States contributed to the total production of 169,761,000 brick, valued at $2,490,283. Pennsylvania ranked sixth with a production of 10,840,000.

Sand-lime brick consists of about 85 per cent sand and 15 per cent hydrated lime. These two ingredients mixed with sufficient water to permit molding are pressed into shape and then cured by subjection to steam under pressure of 100 to 150 pounds for 7 to 12 hours. A chemical reaction takes place, producing amorphous monocalcium silicate ($CaOSiO_2$), which binds together the remaining sand particles. High calcium lime is better than magnesian lime in that it produces brick of greater strength. Complete hydration of the lime is essential and this is more readily accomplished with the high calcium variety. Alumina, if not more than 2½ per cent, is not objectionable and silica in the lime is likewise harmless if proper allowance is made for it.

The brick are white, unless artificially colored, and possess about the same hardness and porosity as ordinary clay building brick. They are more regular in shape and size than burned brick.

CHEMICAL USES OF LIME.

The chemical uses of lime are so extensive that it is not possible to enter into a description of even the most important. Perhaps no other substance is used in as varied manner in the chemical industry. In a paper on "Lime in the Chemical and Allied Industries" Dr. M. E. Holmes,[15] described the various functions of lime as a chemical agent in the following paragraphs quoted.

"Lime is a dehydrating agent. It will combine with the occluded water and the water of constitution of certain chemical substances rendering them anhydrous. For this reason, lime finds use in the manufacture of alcohol, both ethyl and methyl, and in the petroleum refining industry for dehydrating crude petroleum and greases. It, therefore, commends itself to the attention of every manufacturer employing processes of dehydration.

"Lime is a coagulating agent. A suspension of lime contains charged particles which will neutralize the charge of colloidal material flocculating it and clarifying the liquid by 'settling out'. It is due to this specific property of lime that it finds extensive application in the sugar industry. It is used for defacating raw sugar juices, a process which is accelerated by carbonating and sulphitating the lime in suspension. The carbonated lime in settling carries with it flocculated and absorbed colloidal matter producing a clear clarified juice.

"The coagulating capacity of lime finds use for itself in the mining industry. Ore slimes are made to coagulate and settle rapidly by flocculation with lime. The efficiency of the process is thereby greatly increased through reducing the time of operation. The use of lime in the artificial ice industry also depends upon the coagulating capacity of lime. Water suitable for artificial ice must be clarified and purified and the satisfactory process for this is the use of lime in combination with other reagents.

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[15] Rock Products, Vol. 24, No. 19, pp. 17-19, Sept. 1921.

"Lime also finds use as a flocculating agent in the rubber industry. The latex may be flocculated with lime and the clays used in making the compounding ingredients are flocculated with lime to render them suitable as a filler for the rubber. The use of lime in the sorghum industry also depends upon its coagulating capacity. The sorghum juice is clarified with lime in preparing it for the boiling operation. The coagulating action of lime is also employed in the disposal of sewage whereby the sewage is clarified by coagulating the colloidal matter with lime in combination with other chemical substances. Similarly water supplies may be deodorized and deferridized. Waste waters are also coagulated and disposed of with the use of lime. The coagulating action of lime is one of its most important properties and its uses by virtue of this property are very numerous.

"Lime functions as an absorbent for gases. Being a basic substance it will readily absorb practically all acid gases. This property of lime makes it useful in the electrolytic-alkali industry in which it is used to absorb and combine with chlorine in making bleaching powder, alkali hypochlorites and chlorates. It is the absorbing capacity of lime which makes it useful in the fixation of atmospheric nitrogen, where it is used to absorb nitrogen oxides in making nitric acid. Lime also finds use in the paper industry. As a result of its capacity for absorbing gases, lime will absorb sulphur dioxide forming bisulphites and sulphites which are used for making paper pulp. For the same reason lime is used in purifying illuminating gas in which process it absorbs sulphur dioxide, hydrogen sulphide and hydrocyanic acid, rendering the gas non-corrosive to boilers and metal fixtures. The absorption of carbon dioxide by lime is a process employed in the carbonation of sugar juices and in the manufacture of magnesia insulating material and in the manufacture of phenol. In the wood distillation industry the absorption of acetic acid vapor by lime produces acetate of lime. Acetic acid may then be made from the acetate by distillation with sulphuric acid.

"Lime is a causticizing agent. As such it is used in reacting with alkali sulphates, carbonates and phosphates forming hydroxides. This property of lime makes it useful in the paper industry where it is used for making caustic soda for use in the soda and sulphate pulp process. Similarly it is used in making the bases for hypochlorites in the bleaching industry, and alkali salts in general in the inorganic chemical industry. The various hydroxides made by causticizing with lime can be combined with the many acids forming a long array of inorganic salts. The causticizing action of lime is employed in the soap industry. Soaps are alkali salts of organic acids made from hydroxides produced by causticizing with lime. The causticizing action of lime is employed in the textile industry also wherein cloth fibers are mercerized with alkalies produced by the caustic action of lime.

"Lime is a hydrolizing agent. As such it is employed in the manufacture of hydrolized glue which is used in the prevulcanization treatment of rubber. By hydrolysis of aluminum nitride the compound is decomposed forming ammonia. This is a part of a process that may develop into an important means of fixing atmospheric nitrogen. The hydrolytic action of lime is also used in treating cellulose for the manufacture of material suitable for making a pulp cloth.

"Lime is a saponifying agent. As such it is used in the treatment of fats, waxes and greases whereby organic compounds such as glycerine may be "split off" and the alkaline-earth salts of the fatty acids produced. By this process the animal products industries produce glycerine, glues, soaps, lubricating greases and paints. Lime cleanses wool and unhairs hides. Lime is also used in saponifying oils and in making lubricating greases and tar products and for making roofing material and waterproofing compositions. Lime is used also to saponify organic salts and in making organic hydroxides in the dye and organic chemical industry.

"Lime is a solvent. As such it is used in the treatment of hides whereby the cementing material is disintegrated and removed. For this reason along with others it finds extensive use in the tanning industry. Lime will also dissolve casein and as such it is used largely in the cold water paint industry. Lime in fused slag will dissolve sulphur and phosphorus and thus it finds use in the metallurgical industry for purifying steel and other metals.

"Lime is an oxidizing agent. As such it is used in the electrothermic industry where it oxidizes carbon thereby reducing itself, forming calcium carbide. Similarly lime has been used in a simple laboratory way for making metallic calcium. Of much more importance, however, is the manufacture of calcium silicide whereby lime functions indirectly as an oxidizing agent.

"Lime is a reducing agent. As such it is used in the manufacture of calcium peroxide by reduction of hydrogen peroxide or other strong oxidizing agents. This is one of the newer uses of lime which may have important possibilities.

"Lime is a lubricating agent. As such it is used in the high temperature lubrication of dies in the drawing of steel wire. Its fineness and refractoriness make it especially suitable for this use.

"Lime is a fluxing agent. As such it is used extensively in the basic open hearth process for refining steel, and for the manufacture of pottery and porcelain in the ceramic industry.

"Lime is a catalyzing agent. It functions as such in the peroxidation of alkalies forming such products as sodium peroxide. It also catalyzes the formation of calcium cyanamide in the action of calcium carbide on nitrogen. Lime also catalyzes the vulcanization of rubber, and the hydrogenation of nitrogen in the Haber process of fixing atmospheric nitrogen. In the fusion of chromite with alkalies, lime functions as a catalyst in the preparation of alkali dichromates. The esterification of glycerine and the manufacture of chlorine in the Weldon chlorine process also involve the catalytic action of lime.

"Lime is an ionizing medium, whereby it finds application in the production of metals by electrolysis of fused metals and in the electrical method of sewage disposal.

"Lime is a refractory. Its melting point and sintering point are exceeded by only a very few substances. It finds use, therefore, as such in the manufacture of dead burned dolomite, silica brick and the like as refractory lining for furnaces and as insulating material for steam pipes.

"Lime is a precipitating agent. As such it finds extensive use in the preparation of many inorganic and organic salts, in the winning of metals from ores, and the preparation of rare earth oxides from monazite sand, in the preparation of absorption media such as iron hydroxide in the purification of water and in the preparation of colloidal pigments such as satin white.

"Lime functions in various capacities in distillation. Lime is used in the distillation of coal and oil shale to produce ammonia and ferro-cyanides and to enrich and purify the coal gas. In the wood distillation industry lime is used in the distillation of pyroligneous acid in making aluminum acetate, acetic acid, acetone and methyl alcohol. The distillation of gas works liquors with lime produces many thousand tons of ammonia yearly.

"It is futile to attempt to cover in one brief article all of the functions of lime as represented by its manifold uses. It would not be permissible, however, in any article on this subject to omit the use of lime as a base or neutralizing agent. As mentioned above, lime is the queen of bases and by virtue of its composition [CaO and $Ca(OH)_2$] belongs to that class of chemical substances called hydroxides which will neutralize acids. Lime is used for neutralizing resinous acids for use in making varnish and enamels in the paint industry, and for use in making stabilizing media for liquid fuels. Ores are neutralized with lime in ore flotation and in the cyanide process in the mining industry.

"Organic acids are neutralized with lime in making lubricants, oil cloth and candles. Tar acids are neutralized with lime in making roofing material, bituminous paint, sulphonate detergents and lubricants in the hydrocarbon industry. The citrate industry employs the use of lime for neutralizing and recovering citric acid. Arsenic acid is neutralized with lime in making calcium arsenate in the insecticide industry. The manufacture of many mineral products involves the use of an excess of acids which is neutralized with lime. In the dye industry excess acids must be neutralized in the manufacture of phenol, sulphonated napthalene and anthracene. In the explosive industry excess acid is neutralized with lime in the manufacture of nitroglycerine. In making saccharified cellulose such as sawdust cattle food, excess acid used in hydrating the woody material is neutralized with lime. In like manner the acids used in pickling steel are neutralized with lime and the residual acids in Keenes cement and dried leather may be rectified with the use of lime."

In the accompanying chart, prepared by the National Lime Association, the chemical uses of lime are classified under the following divisions.

A. Raw materials in the manufacturing industries.

1. High temperature processes
2. Saponification
3. Dehydration
4. Hydrolysis
5. Causticization
6. Coagulation
7. Absorption of gases
8. High-pressure
9. Distillation
10. Precipitation
11. Neutralization
12. Solution
13. Miscellaneous

B. Sanitation

1. Treatment of water supplies
2. Treatment of sewage
3. Miscellaneous sanitary uses

C. Purification of materials

D. Food for animals and plants

E. Catalytic processes

F. Utilization of by-products

G. General utility

H. Medicine

I. Miscellaneous

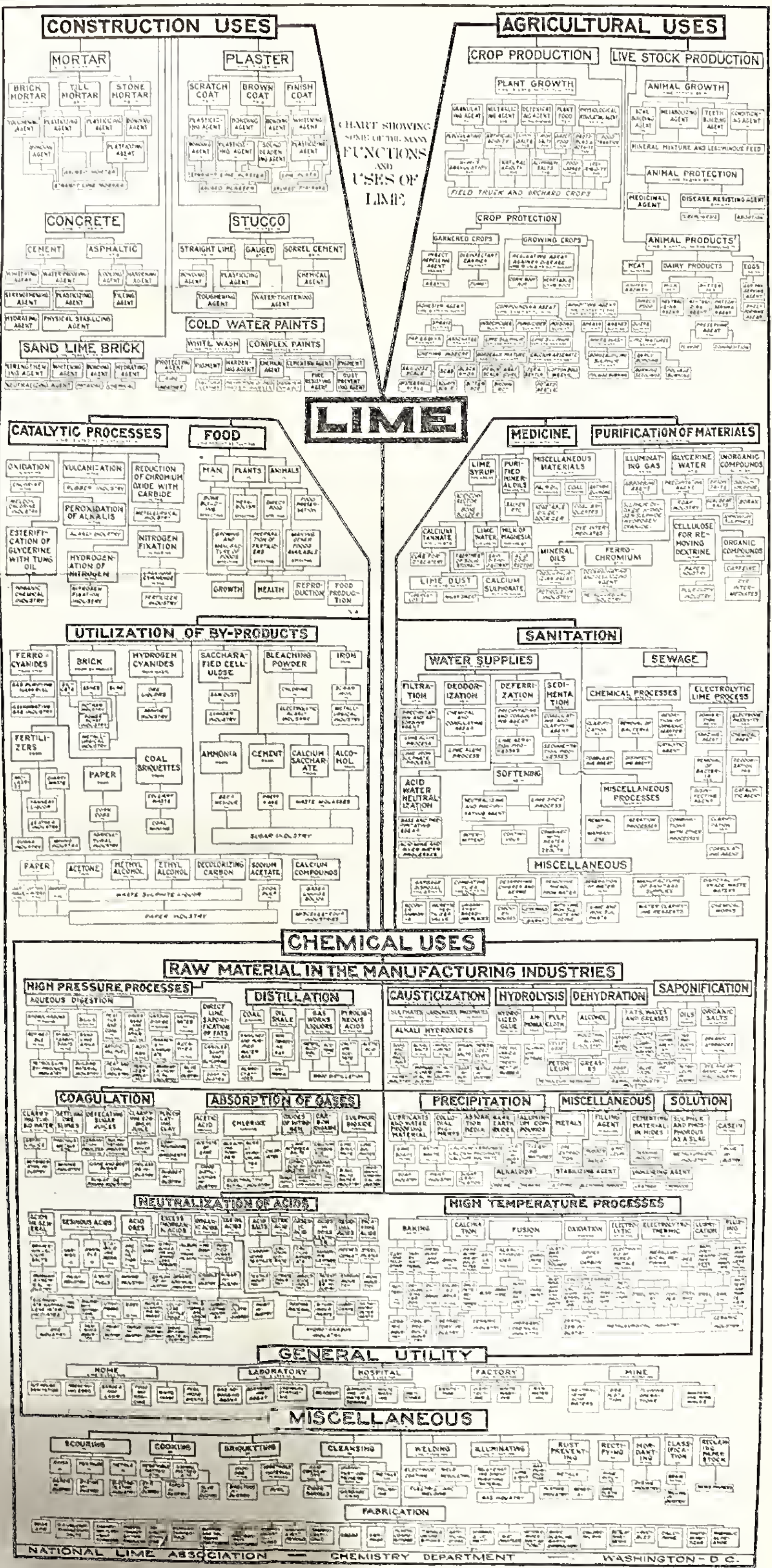

Figure 1. Chart showing some of the many functions and uses of lime.

For most of the chemical uses the demand is for lime of a high degree of purity, but this is not true in some instances. In general limestone used for the manufacture of chemical lime should not contain more than 5 per cent of impurities. Similarly there is usually a preference for high calcium lime, yet there are some cases where a high magnesium lime is more valuable and still others where either type is equally acceptable. Emley[16] gives the following table in which "c" indicates high-calcium lime and "m" magnesian or dolomitic lime.

Chemical Uses of Lime.

- Agricultural industry:
  - As a soil amendment, c, m.
  - As an insecticide, c, m.
  - As a fungicide, c, m.
- Bleaching industry:
  - Manufacture of bleaching powder, "Chloride of lime," c.
  - Bleaching and renovating of rags, jute, ramie, and various paper stocks, c, m.
- Caustic alkali industry:
  - Manufacture of soda, potash, and ammonia, c.
- Chemical industries:
  - Manufacture of ammonia, c.
  - Manufacture of calcium carbide, calcium cyanimid, and calcium nitrate, c.
  - Manufacture of potassium dichromate and sodium dichromate, c.
  - Manufacture of fertilizers, c, m.
  - Manufacture of magnesia, m.
  - Manufacture of acetate of lime, c.
  - Manufacture of wood alcohol, c.
  - Manufacture of bone ash, c, m.
  - Manufacture of calcium carbides, c.
  - Manufacture of calcium-light pencils, c.
  - In refining mercury, c.
  - In dehydrating alcohol, c.
  - In distillation of wood, c.
- Gas manufacture:
  - Purification of coal gas and water gas, c, m.
- Glass manufacture:
  - Most varieties of glass and glazes, c.
- Milling industry:
  - Clarifying grain, c, m.
- Miscellaneous manufactures:
  - Rubber, c, m.
  - Glue, c, m.
  - Pottery and porcelain, c, m.
  - Dyeing fabrics, c, m.
  - Polishing material, c, m.
- Oil, fat, and soap manufacture:
  - Manufacture of soap, c.
  - Manufacture of glycerine, c.
  - Manufacture of candles, c.
  - Renovating fats, greases, tallow, butter, c, m.
  - Removing the acidity of oils and petroleum, c, m.
  - Lubricating greases, c, m.
- Paint and varnish manufacture:
  - Cold-water paint, c, m.
  - Refining linseed oil, c, m.
  - Manufacture of linoleum, c, m.
  - Manufacture of varnish, c, m.
- Paper industry:
  - Soda method, c.
  - Sulphite method, m.
  - For strawboard, c, m.
  - As a filler, c, m.
- Preserving industry:
  - Preserving eggs, c.
- Sanitation:
  - As a disinfectant and deodorizer, c.
  - Purification of water for cities, c.
  - Purification of sewage, c.
- Smelting industry:
  - Reduction of iron ores, c, m.
- Sugar manufacture:
  - Beet root, c.
  - Molasses, c.
- Tanning industry:
  - Tanning cowhides, c.
  - Tanning goat and kid hides, c, m.
- Water softening and purifying, c.

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[16] Emley, Warren E., Manufacture and use of lime: U. S. Geol. Surv. Mineral Resources, 1913 Pt. II, pp. 1592-1593, Washington, 1914

Silica and alumina are undesirable constituents of limestone used for the manufacture of chemical lime as they serve either to dilute the product or else in burning may unite to form insoluble silicates which have a tendency to form sinter and interfere with the calcining of the carbonate. Iron in any form is undesirable in that it may behave as do silica and alumina and in addition it discolors the lime.

Since the amount of lime required by any one plant is usually relatively small, naturally there is rather strenuous insistence that the product conform to the specifications.

Pennsylvania is fortunate in the possession of several areas of high grade limestone well adapted for the manufacture of chemical lime.

STATISTICS OF USES OF LIME IN THE UNITED STATES.

The following tables are from the chapter on lime in Mineral Resources of the United States, 1922, published by the United States Geological Survey.

Lime sold in the United States in 1921 and 1922, by uses.

Use	Percentage of total quantity	Short tons	Value	
			Total	Average
1921				
Building	49.0	1,239,486	$13,258,443	$10.70
Agricultural	11.2	284,722	2,237,510	7.86
Chemical:				
Paper mills	9.3	235,855	2,207,938	9.36
Glass works	1.7	43,851	367,796	8.39
Sugar factories	.5	12,225	161,931	13.25
Tanneries	1.9	47,841	481,372	10.06
Metallurgy	6.5	164,245	1,232,748	7.51
Other uses*	18.0	456,087	4,372,991	9.59
Total chemical	37.9	960,104	8,824,776	9.19
Dealers	1.9	47,841	574,641	12.01
	100.0	2,532,153	24,895,370	9.83
Hydrated lime (included in totals)		792,970	7,421,637	9.36
1922				
Building	50.7	1,845,208	18,463,825	10.01
Agricultural	7.5	272,726	2,005,082	7.35
Chemical:				
Paper mills	8.5	310,229	2,683,487	8.65
Glass works	1.7	62,187	463,628	7.46
Sugar factories	.5	16,393	197,878	12.09
Tanneries	1.2	42,978	420,148	9.78
Metallurgy	5.5	200,799	1,458,553	7.26
Other uses*	22.9	834,279	6,986,366	8.37
Total chemical	40.3	1,466,865	12,210,060	8.32
Dealers	1.5	54,818	576,072	10.51
	100.0	3,639,617	33,255,039	9.14
Hydrated lime (included in totals)		1,106,063	9,868,980	8.92
Percentage of increase or decrease of hydrated lime in 1922		+39	+33	—5

*Details of distribution shown in following table.

Chemical lime sold for "other uses" in 1921 and 1922.

Use	1921		1922	
	Short tons	Value	Short tons	Value
Refractories	107,664	$1,113,010	345,838	$2,813,940
Alkalies	*1,589	*14,190	4,275	33,823
Water purification	74,201	741,264	87,452	802,383
Sanitation	-----	-----	2,048	16,480
Calcium carbide	19,597	173,849	(†)	(†)
Bleaching powder	12,551	131,803	20,979	202,308
Calcium acetate	3,776	32,791	13,500	121,788
Silica brick	7,127	61,738	11,707	95,772
Sand-lime and slag brick	5,464	50,851	28,612	256,280
Ammonia works	8,167	75,206	11,847	100,848
Lubricating-grease manufacture	9,584	102,942	3,975	40,655
Coal and water gas purification	2,408	24,951	1,303	14,665
Coke-oven by-products	3,660	33,257	6,370	51,505
Gas-plant by-products	3,582	35,978	6,668	51,532
Soap manufacture	14,249	119,322	19,613	140,135
Glue manufacture	4,014	37,429	4,946	43,066
Spraying	6,800	70,689	8,950	89,445
Cyaniding	5,185	50,737	-----	-----
Paint manufacture	‡1,443	‡15,530	‡2,503	‡23,234
Wood distillation	2,472	19,508	5,963	46,278
Sewage purification	3,422	33,412	2,073	17,931
Corn products	1,117	9,978	(†)	(†)
Gelatin manufacture	1,287	15,892	(†)	(†)
Dairy products	735	2,922	246	2,701
Rubber manufacture	723	10,455	1,923	23,443
Correction of acidity of oils	587	3,917	934	12,216
Salt refining	1,072	10,647	1,278	11,734
Flour mills	(†)	(†)	225	3,234
Disinfectant	1,182	10,223	737	7,146
Manufacture of candles	180	1,701	(†)	(†)
Undistributed§	10,814	101,573	12,810	124,610
Unspecified	141,635	1,267,106	224,524	1,839,348
	456,087	4,372,991	834,279	6,986,376

* All noncommercial production omitted and included in report on stone as limestone.
† Included under "Undistributed."
‡ Includes kalsomine.
§ Includes in 1921 lime used in the manufacture of precipitated calcium carbonate, indigo, graphite products, varnish, nitrates, food products, polishing and buffing compounds, magnesia, pottery, textiles, dyes, oxygen, medicine, for the renovation of grease, neutralization of acid waters, distillation and dehydration of alcohol, separation of ores, use in flour mills, and for mixture with wood ashes; in 1922, lime used in the manufacture of precipitated calcium carbonate, glycerin, dyes, oxygen, potash, candles, varnish, corn products, gelatin, buffing compounds, gypsum products, proprietary medicine, calcium carbide, explosives, basic magnesium carbonate, distillation and dehydration of alcohol, use in print mills, and for mixture with wood ashes.

PREPARATION OF LIME.

The method of burning lime has received much attention during the last few years. In some outlying districts in Pennsylvania the burning is still done in the open (Plate I, B) by piling up alternate layers of wood or bituminous coal and blocks of limestone so arranged as to cause a good draft. When the fuel is well ignited, earth is thrown over the top.

The home-made rock "pot" kiln has had wide use and in many sections there is one on almost every farm where the necessary lime for farm use was burned. These are now being abandoned and the farmer buys his lime as needed.

Shaft kilns in which there is an outer casing of steel or stone and an inner lining of refractory material are now in general use. Rotary kilns similar to those used in Portland cement mills are also used but only when hydrated lime is produced because the stone for a rotary must be crushed so fine that no lump lime can be made.

Lime is marketed as ground quicklime, unslaked lump lime, and hydrated lime. For some purposes it is optional as to which is used but in certain manufactures the requirements demand one particular kind. Lump lime is ordinarily shipped in wooden or steel barrels, ground quicklime in air-tight iron casks, and hydrated lime in paper bags, sacks, or barrels.

Hydrated lime is made at the plant by passing the ground quicklime through patent hydrators, of which there are two kinds widely used. In them the exact amount of water necessary for complete hydration is added and the material constantly stirred during the process to thoroughly mix the water and lime. The product is decidedly superior to that obtained in the usual process where lump lime is slaked in a box by stirring with a hoe. Hydrated lime also undergoes carbonation or air-slaking more slowly and can be kept longer and shipped more freely.

A typical flow-sheet of the process of making pulverized limestones, quicklime, and hydrated lime, prepared by the National Lime Association is reproduced as Figure 3. Several lime plants in Pennsylvania are built in conformity with this scheme.

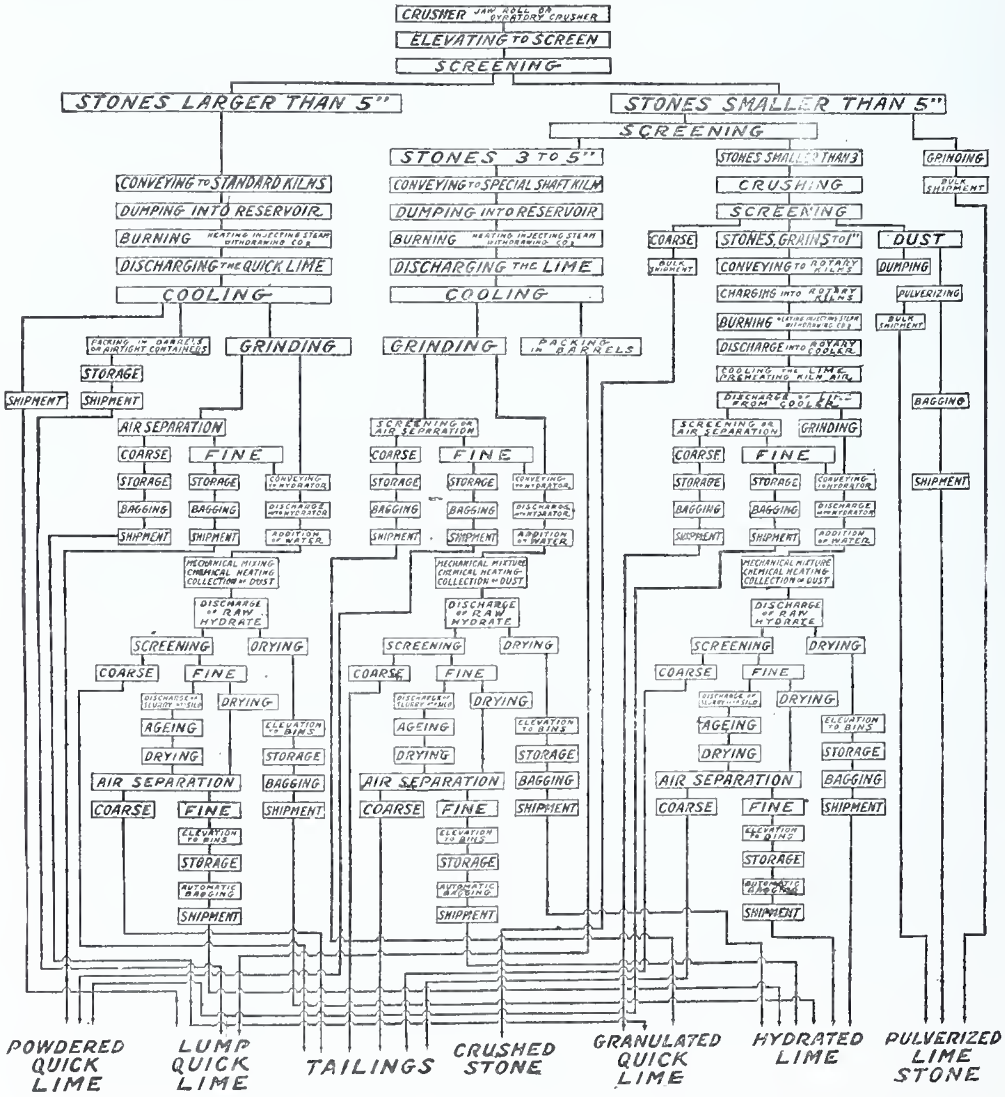

Figure 3. Flow sheet showing process of making pulverized limestone and lime.

CHAPTER II.

LIMESTONE RESOURCES OF PENNSYLVANIA

GEOGRAPHIC AND GEOLOGIC DISTRIBUTION.

Limestones are fairly well distributed throughout the State although there are some sections in which they are so thin or so impure that they possess little economic importance. In general the limestones of value are confined to the southern two-thirds of the State, exclusive of the anthracite regions and the eastern portion of the bituminous coal areas. The largest areas of high grade limestones are in the central and southeastern parts and the greater production is from Montgomery, Chester, Lancaster, York, Adams, Northampton, Lehigh, Berks, Lebanon, Dauphin, Cumberland, Franklin, Centre and Blair counties.

The southwestern counties contain many limestones but they are in general impure and of little more than local importance. North and northeast of Pittsburgh the valuable Vanport limestone is present in several counties but the quantity of this stone available is insignificant in comparison with the thick strata contained in the southeastern counties named.

Geologically, limestones, as shown in the accompanying table of Pennsylvania formations, are present in each of the major groups. It will readily be noticed, however, that the Cambrian, Ordovician, uppermost Silurian, lower Devonian, and Carboniferous contain practically all the workable limestones.

The accompanying map of the State showing the distribution of the principal limestones is based on the geologic occurrence in large part. A map based on the chemical or physical character or the uses for which the limestones are best adapted is not practicable because of the variability of the stone and the variety of uses for the same stone. A series of maps, one for each use, would be necessary to show the distribution of the limestones according to their adaptabilities.

On a general map it is not possible to show all the localities where thin limestones outcrop nor to show the location of the hundreds of quarries that have been opened. Indeed it has not been thought profitable to describe all the quarries.

The map shows the surface distribution of the Cambro-Ordovician, and Helderberg (including the Tonoloway) limestone, and the various Carboniferous formations of the western portion of the State. The limestones of the Cambrian and Ordovician are grouped together because of their similarities, their close relationship as the most important series of limestones of the State, and the additional fact that in some places they have not been definitely separated. Their great thickness is responsible for the formation of the great limestone valleys of the central and southeastern portions of the State.

Next in order of importance are the limestones of the Helderberg series (lowest Devonian) and the Tonoloway (uppermost Silurian). These have not been separated in some places and occasionally both are worked in the same quarry so that it seems most useful to map them as a single unit. They are responsible for minor valleys in that portion of Pennsylvania where the rocks have been greatly folded and steep ridges and valleys alternate.

In those sections where the Carboniferous strata are developed and contain interbedded limestones the beds are flat or gently dipping and the region dissected by streams that have cut valleys in a dentritic pattern. The limestones forming a small part of the strata, outcrop along the sides of the valleys. Only on very large scale maps could the outcrops of all the limestones be shown and in many places the information for such maps is not available nor could it be obtained without much additional field work. For these reasons it has been thought best to show the distribution of the various formations of Carboniferous age. Limestones are found in each of the various formations but as described in the text the Allegheny, Monongahela, and Washington formations contain practically all those of economic importance.

GEOLOGIC TIME SCALE OF PENNSYLVANIA STRATA SHOWING OCCURRENCES OF LIMESTONES.

Age-System	Period-Series	Epoch-Group	Development of limestones	Uses
Quaternary 1,000,000 years	Pleistocene	Historic Glacial	No limestones	
Tertiary 60,000,000 years	A few local deposits, probably of this age, southeastern part of State		No limestones	
Cretaceous 75,000,000 years	Sparingly represented in the southeastern part of the State		No limestones	
Jurassic 40,000,000 years	No deposits of this age in State			
Triassic 40,000,000 years	Newark		Limestone conglomerate sparingly developed in Berks, Bucks, Cumberland and York counties	Ornamental building stone, lime.

GEOLOGIC TIME SCALE OF PENNSYLVANIA STRATA—Continued.

Age-System	Period-Series		Epoch-Group	Development of limestones	Uses
Carboniferous 115,000,000 years	Permian	Dunkard	Greene	Detailed classification of Carboniferous on later page	Agricultural lime, building lime, flux, cement, crushed stone for concrete and building.
			Washington		
	Pennsylvanian	Pittsburgh	Monongahela	Numerous limestones interbedded with shales, sandstone and coal beds. Limestones numerous in western part of State, especially in southwestern counties	
			Conemaugh		
			Allegheny		
	Mississippian	Mauch Chunk			
		Pocono			
Devonian 50,000,000 years		Upper	Catskill	Thin impure limestone locally developed in Bradford, Lycoming, Potter, Sullivan, Susquehanna, Tioga, Wayne counties	Agricultural lime.
			Chemung	Thin, impure limestones locally developed in Bradford, Potter, Susquehanna, and Tioga Counties	Agricultural lime, flux.
			Portage		
			Genesee		
		Middle	Hamilton	Thin, impure limestones locally developed in central part of State	Agricultural lime.
			Marcellus	Thin, impure limestones locally developed in central part of State	Agricultural lime.
			Onondaga (Corniferous)	Cherty limestones from 0 to 200 feet in thickness developed in Carbon and Monroe counties	Lime and cement.
		Lower	Oriskany	Siliceous limestones developed in a few places in south central part of State	Agricultural lime.
			Helderberg	Valuable limestones outcropping in Bedford, Blair, Carbon, Centre, Clinton, Columbia, Franklin, Huntingdon, Juniata, Lebanon, Lycoming, Mifflin, Monroe, Montour, Northumberland, Perry, Schuylkill, Snyder and Union counties	Lime (agricultural, building chemical), flux
Silurian		Upper Cayuga			

GEOLOGIC TIME SCALE OF PENNSYLVANIA STRATA—Continued.

Age-System	Period-Series	Epoch-Group	Development of limestones	Uses
Silurian 40,000,000 years (continued)	Cayuga	Tonoloway	Outcrops with Helderberg limestone	Lime (agricultural building, chemical), flux.
		Salina	Impure limestones locally developed in Montour County	Agricultural lime.
	Niagara	Lockport Clinton	Thin, impure limestones in central part of State	Agricultural lime.
	Medina	Tuscarora Juniata Oswego		
Ordovician 110,000,000 years	Cincinnati Mohawk Chazy Beekmantown	Cambro-Ordovician limestones See detailed classification on later page.	Limestones from 4,000 to 11,000 feet in thickness extensively developed in Adams, Bedford, Berks, Blair, Bucks, Centre, Chester, Clinton, Cumberland, Dauphin, Franklin, Fulton, Huntingdon, Juniata, Lancaster, Lebanon, Lehigh, Lycoming, Mifflin, Montgomery, Northampton, and York counties.	Lime (agricultural, building, chemical) flux (dolomitic and non-dolomitic), cement, crushed stone for concrete and road metal, building stone, etc.
Cambrian 90,000,000	Ozarkian St. Croixan Acadian Waucoban			
Algonkian ? years	Keweenawan Huronian	Peters Creek schist Wissahickon gneiss		
		Cockeysville marble	Locally developed in Chester County	Lime, flux, cement, and building material.
Archean ? years	Laurentian	Franklin limestone	Locally developed in Berks, Bucks, Chester, and Northampton counties	Lime and building material.
	Keewatin	Pickering gneiss Baltimore gneiss		

CHAPTER III.

PRE-CAMBRIAN LIMESTONES.

STRATIGRAPHIC POSITION.

Pre-Cambrian limestones, more or less completely metamorphosed to marbles, occur in several localities in Chester, Bucks, Berks, and Northampton counties. There has been much discussion concerning their stratigraphic position but as the result of field conferences participated in by a number of geologists who are most familiar with the geology of the Piedmont Plateau the following classification has been adopted. The quoted descriptions have been furnished by F. Bascom.

Pre-Cambrian formations of Southeastern Pennsylvania.

Late pre-Cambrian.

- Peters Creek schist ("chloritic sericitic quartz schists with chlorite muscovite schists").
- Wissahickon formation ("thoroughly crystalline quartz-feldspar mica rock; gneiss and mica schist. A mica schist facies was formerly known as the Octoraro mica schist and regarded as Ordovician in age").
- Cockeysville marble. ("coarsely crystalline, associated with gneiss and penetrated by pegmatites").
- Setters quartzite ("occasional and limited development of quartzite beds; in some places dominantly a mica gneiss").

Early pre-Cambrian.

- Franklin limestone or marble ("coarsely crystalline, white with graphite and numerous silicate minerals.").
- Pickering gneiss (banded gneiss or schist containing lenses of highly graphitic schists).
- Baltimore gneiss ("sedimentary, medium to fine grained, banded gneiss with igneous intrusives. In some places thoroughly granitized").

With the above classification, now adopted by the U. S. Geological Survey, the writer is in agreement except with regard to the separation of the Franklin limestone and Pickering gneiss as two distinct formations. Observations at several places in the Piedmont Plateau lead him to believe that they constitute a single formation similar to the Grenville formation of New York and Canada. He has discussed this problem in a previous publication[17] as follows:

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[17] Miller, B. L., Graphite Deposits of Pennsylvania, Topographic and Geologic Survey of Pennsylvania, Report 6, pp. 81-82, 1912.

"Relation of the Franklin Limestone and the Pickering Gneiss.

In the above discussion the Franklin limestone and Pickering gneiss have been discussed as separate formations and it is probably advisable to map them as such because of the different economic uses of the two. Also in many places there seems to be a sharp line of separation between them. In other places, however, it is not possible to draw a sharp line and we have calcareous graphitic gneisses that might with equal reason be placed in either formation. We seem to have a duplication of the Grenville series of the Adirondack region where limestones, gneisses, schists, and quartzites occur in almost inextricable relationships. The workable graphite deposits of that state are contained in the Grenville rocks, mainly in the quartzites. These rocks are there believed to represent the metamorphic products of calcareous or siliceous shales. A similar explanation seems to satisfactorily explain the Franklin limestone and Pickering gneiss of Pennsylvania.

"According to the above view the two formations were formed originally as contemporaneous sediments that varied in different places. In some localities fairly pure limestone was being deposited while in adjacent regions calcareous muds or siliceous muds in which there was little or no calcareous material were accumulating. When these sediments were later metamorphosed the beds composed mainly of calcareous matter formed the rocks called the Franklin limestone; the calcareous muds gave rise to the calcareous graphitic gneisses observed in the underground workings of the Pennsylvania and Continental (Acme) mines; the muds with little calcareous matter formed the bulk of the Pickering gneiss; and the more siliceous sediments formed the quartz schists such as occur in the lower levels of the Continental (Acme) mine. The quartz schist or quartzite phase is not well represented in Pennsylvania while in New York it forms perhaps the most important member of the Grenville series from an economic standpoint.

"On the surface the relations described above are not readily apparent because of the solution of the greater part of the calcareous matter in the originally calcareous graphitic gneiss by percolating waters. We thus have outcropping only the two kinds of materials, the relatively pure crystalline limestone and the decomposed graphitic gneiss, consequently the line of separation between them seems to be rather sharp. Underground, however, where solution has been less effective the two grade into each other through the calcareous gneiss.

"Although bedding planes are not apparent in the Franklin limestone it seems probable that the limestone and gneiss are conformable. This conclusion is based on the fact that the limestone occurs in lenticular masses with the greatest length parallel to the strike of the gneiss beds in some localities and probably such relations would be found to exist in other places as well if it were possible to obtain the necessary data. If, then, we can prove that the two formations are conformable, with the Franklin limestone intercalated within the Pickering gneiss, we have sufficient evidence for the view expressed above that the two are of contemporaneous origin and represent merely different lithologic phases of the same series of sediments."

FRANKLIN LIMESTONE.

The Franklin limestone, or the calcareous phase of the Franklin or Grenville formation, is developed in several very small areas in Chester, Bucks, Berks and Northampton Counties.

Chester County.

The Franklin limestone is best developed in Chester County where F. Bascom has mapped four small areas in the Pickering Valley and three in the valley of French Creek. In addition it has been observed in the underground workings of some of the graphite mines of Chester County as mentioned in the above quotation.

The Franklin limestone of Chester County has been quarried to a small extent for agricultural lime but the presence of considerable silicate material has caused the abandonment of all the quarries.

This limestone is very coarsely grained, in certain places the individual particles being as much as an inch in diameter. Graphite, or graphite and phlogopite, in small flakes about one-eighth inch in diameter are rather evenly distributed throughout the rock but with no regularity or apparent order of arrangement where other minerals are absent. But, in certain places, the marble is very impure and various silicates, particularly the basic ones are present and they are arranged in approximately spherical or globular segregations varying from a few inches to several feet in diameter. The graphite associated with such segregations is usually in much larger flakes, in places as much as one-half inch in diameter. Many of the flakes show distinct hexagonal outlines.

Bucks County.

The only place where the Franklin limestone outcrops in Bucks County has been described by F. Bascom[18] as follows:

"One mile southeast of Holland and three-fourths mile west of Neshaminy River there is a very small area of limestone, which, because of its character and associations, is assigned to a pre-Cambrian horizon.

"The limestone is exposed only in the walls of an abandoned quarry, known as the Vanartsdalen quarry, which was opened about fifty years ago and was operated for thirty years. Sink holes in line with the strike of the limestone indicate that the rock underlies about 10 acres. Limestone is reported in the bed of the Neshaminy, where the new bridge for the Pennsylvania Railroad crosses that creek; this location is continuous with the strike of the quarry rock.

"The quarry rock is a coarsely crystalline marble, white when pure but usually darkened by the presence of graphite and silicate minerals. Thirty mineral species have been attributed to this locality. The most abundant of the silicates are the feldspars (orthoclase, oligoclase, and bytownite), scapolite, titanite, and phlogopite; apatite and siderite are also common. The marble is surrounded by and thoroughly injected with gabbro. To this association the rock probably owes its high degree of crystallinity. Along the contact zone augite and hornblende are abundantly developed in the calcareous rock, while calcite veins and inclusions characterize the igneous rock.

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[18] U. S. Geol. Survey, Trenton Folio, No. 167, pp. 4-5, 1909.

"The limestone of the Vanartsdalen quarry sustains no stratigraphic relations with any formation, and it is therefore impossible to determine with precision the horizon to which it belongs. That it is presumably pre-Cambrian is indicated by the intrusion in it of igneous material which elsewhere is confined to pre-Cambrian formations.

"In color, perfection of crystallization, and the presence of graphite and silicate minerals, the rock resembles the pre-Cambrian Franklin limestone which outcrops 70 miles to the northeast in New Jersey, and it not improbably represents a remnant of that formation left by erosion."

Berks County.

In a previous report[19] the writer has described an occurrence of Franklin limestone in Berks County as follows:

"Graphite occurs in gneiss and Franklin limestone at the Bittenbender Iron Mine, one-half mile northeast of Seisholtzville. The mine has furnished a large amount of high-grade magnetite ore but has not been operated for several years. No graphite has ever been mined at this place but its abundant and varied occurrence warrants a brief description. It furnishes another illustration of the intimate connection existing between the Franklin Limestone and the graphitic gneiss of Pennsylvania.

"No observations could be made of the various graphite-bearing rocks in place and the following information was obtained through a study of the rocks on the waste heaps near the mine opening.

"Many specimens of white crystalline limestone with flakes of graphite ¼ inch in diameter, irregularly disseminated, were seen on these waste heaps. The flakes show no regularity of arrangement. Some of the limestones seem to have been altered to silicate rocks with segregations of augite, graphite, and an asbestiform mineral.

"Other rocks consist of dark red garnet, hornblende, augite, and graphite. Specimens of massive magnetite were observed in which there were occasional partings of graphite. Some of the rocks consist of massive hornblende, augite, some hypersthene, and graphite flakes. Gneiss such as occurs in other graphite areas is also present in which the mass of the rock is composed of plagioclase, quartz, augite, and flakes of graphite ⅛ inch in diameter. Pegmatites composed of orthoclase, quartz and large graphite flakes are represented by occasional specimens.

"In no other place in the State is there such a variety of graphitic rocks so that it is especially unfortunate that their relations are not known. It is improbable that any of them could ever be profitably worked for graphite."

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[19] Op. cit., pp. 113-114.

Northampton County.

About 2½ miles north of Bethlehem, on the west side of Monocacy Creek an outcrop of Franklin limestone covers a few acres. The limestone is completely metamorphosed to a coarse-grained white marble containing numerous graphite flakes and many silicate minerals as in the localities described above. It is intimately associated with graphitic schist and gabbro although the exact relations of these rocks cannot be determined from the outcrops.

A few years ago a quarry was opened along the creek and considerable stone was shipped to some of the cement mills in the vicinity that require additional high calcium limestone low in magnesia. The rock in this quarry is so crushed and sheared and contains such an unusually large amount of silicate minerals that it was necessary to discard a considerable quantity of the stone and the quarry did not prove profitable. From the surface indications it would seem probable that much better material could be obtained from other parts of the property. An average analysis of 50 tons of stone gave the following results $CaCO_3$—90.49, $MgCO_3$—2.10, SiO_2—7.39 (see pp. 123-124)

COCKEYSVILLE MARBLE.

There are several small areas of Cockeysville marble in the southeastern part of Chester County where several marble quarries were long operated. In recent years there has been little quarrying done and the large openings are filled with water. The limestone is developed in the vicinity of Doe Run, Avondale, and Landenberg.

Bliss and Jonas[20] have described the region as follows:

> "In the central and southern parts of the Doe Run district limestone occurs in four distinct areas of irregular conformation. The largest area extends from Buck Run almost due south to Doe Run village, where the outcrop is pierced by an anticlinal hill of resistant quartzite. From Doe Run southwest to Green Lawn there is a continuous outcrop of limestone, and from Springdell directly south limestone joining the western flank of the quartzite occurs in a long valley that extends to the southern edge of the Doe Run district.
>
> "On the northern and northeastern boundary of the quartzite the limestone occurs in two small but distinct outcrops at Guest's and Logan's quarries. The fourth occurrence is a narrow and irregular outcrop along a tributary of Brandywine Creek, about 2 miles northeast of Logan's quarry and 1 mile north of Upland.
>
> "Except where it borders the quartzite the limestone of these areas is surrounded by the Wissahickon mica gneiss, thereby producing a radial and finger-like arrangement of the surface outcrops which is particularly striking.
>
> "In the Avondale district the limestone occupies the valley of White Clay Creek about Avondale and to the north, and the valley of West Branch of White Clay Creek and its tributaries near Landenberg. The areas are not more than half a mile wide and are

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[20] U. S. Geol. Surv. Prof. Paper 98, pp. 18-19, Washington, 1917.

very irregular. The northern area extends southwestward for about 5 miles from the center of the eastern border of the Coatesville quadrangle; then it turns south and curves about a hill of mica gneiss which lies north of Westgrove; from that point it extends southward through Baker and southeastward to Avondale, where it connects with two belts of the formation—one from the east along Trout Run and the other from the north. About a mile south of Landenberg there is a small area of limestone extending southeastward along Broad Run and across White Clay Creek almost to West Branch. It is not more than a mile wide anywhere, and does not appear at the surface except at Nevin's quarries.

"As there are no natural outcrops of the limestone, its extent is best determined by the soil it makes—a red clay such as is formed by the weathering of a magnesian lime rock. It is exposed for the most part in abandoned quarries which are partly filled with water; the rock forming the walls may be fresh or partly disintegrated into calcareous sand or almost entirely covered by a talus of soil. In the region of Baker and Avondale there are large quarries which are now being operated in this rock and which furnish valuable marble and building stone.

"The strike of the formation ranges between N. 60° E. and N. 70° E. The direction of dip is generally southeast, the only prominent exception being a northwest dip found in a small quarry just north of Westgrove. The angle of dip is low, varying from 20° to 25°.

"Where pure the fresh rock is a medium-grained, highly crystalline lustrous white saccharoidal marble, characterized by the abundant development of various accessory minerals. Phlogopite, in glistening amber-brown scales, is in some places so plentiful that, on planes parallel to the bedding, the rock may appear to be composed almost entirely of mica. Where the phlogopite occurs in smaller flakes it gives the rock a variegated appearance, which has won for it the name "bastard granite." Biotite, muscovite, tourmaline in large black crystals, magnetite, apatite, and pyrite are common accessory minerals.

"Evidences of pressure seen in the thin section are twinning of the calcite crystals, granulation, and undulatory extinction of the quartz, which occurs in interlocking areas forming a mosaic with calcite.

"In the Avondale district the thickness of the limestone, which does not exceed 1,000 feet, represents only part of the original thickness; the remainder has been removed by erosion."

Analyses of Cockeysville marble.

	1	2	3	4	5
$CaCO_3$	94.27	93.31	84.07	73.48	97.50
$MgCO_3$	1.56	1.85	11.14	15.59	.75
$Fe_2O_3 + Al_2O_3$	.26	.75	----	----	1.04
Insoluble	3.91	4.84	4.76	10.76	.84

All samples from quarry along Philadelphia, Baltimore and Washington Central Branch of Pennsylvania R. R. northwest of Avondale. Nos. 1, 2 and 5, white stone, 3 blue stone, 4 gray stone. Analyses 1, 2 and 3 made by Booth, Blair and Garrett, 4 by Wellman Iron and Steel Co., and 5 by Bethlehem Steel Co.

Columnar section of Cambrian and Ordovician rocks of Pennsylvania.

PERIOD.	First Geological Survey of Pennsylvania	Second Geological Survey of Pennsylvania	U. S. Geological Survey 1892 to 1906.	Cumberland Valley (Stose, 1909)	Northampton, Lehigh, and Berks Counties (Wherry and Miller, 1910 and later.)	Centre County (Moore, 1913 unpublished)	Blair and Huntingdon Counties (Butts, 1918)	Southeastern Pennsylvania (Stose and Jonas 1922.)
ORDOVICIAN	III. Matinal shale and slate	III. Hudson River shale III. Utica shale	Hudson River shale	Martinsburg shale (3000 feet)	Martinsburg shale (3000 feet)	Reedsville shale (1000 feet)	Reedsville shale (1000 feet)	
	II. Auroral limestone		Shenandoah limestone			Trenton limestone	Trenton limestone (200 feet)	
		II. Trenton limestone		Chambersburg limestone (100-750 feet)	Jacksonburg cement limestone (250-600 feet)	Black River group: Rodman limestone Lowville limestone	Rodman limestone (20 feet) Lowville limestone (100 feet)	
		II. Chazy limestone		Stones River limestone (675-1000 feet)		Pamelia limestone Carlim limestone (300 feet)	Carlim limestone (180 feet)	Cocalico shale (1000 ± feet) Conestoga limestone (500 ± feet)
		II. Calciferous limestone		Beekmantown limestone (2500 feet)	Beekmantown limestone (1000 ± feet)	Bellefonte dolomite (1800 feet) Axemann limestone (150 feet) Nittany dolomite (1,100 feet) Stonehenge limestone (800 feet)	Bellefonte dolomite (1000 feet) Axemann limestone (200 feet) Nittany dolomite (1000 feet)	Beekmantown limestone (2500 ± feet)
CAMBRIAN				Conococheague limestone (1600 feet)	Allentown limestone (1500 feet)	Mines dolomite (350 feet) Gatesburg formation (1600 feet)	Larke dolomite (250 feet) Mines dolomite (250 feet) Gatesburg formation (1750 feet)	Conococheague limestone (1500 ± feet)
				Elbrook limestone (3000 feet)		Warrior limestone (450 feet)	Warrior limestone (250 feet) Pleasant Hill limestone (600 feet)	Elbrook dolomite (1000 ± feet)
				Waynesboro sandstones and impure limestone (1000 ± feet)			Waynesboro sandstone (250 ± feet)	
				Tomstown limestone (1000 ± feet)	Tomstown limestone (1000 ± feet)			Ledger dolomite (1000 ± feet) Kinzers formation (150 feet) Vintage dolomite (500-650 feet)
	I. Primal limestone	I. Potsdam (Chiques, Chikis, Hellam or White Spot) sandstone	Chickies quartzite	Antietam sandstone (500-800 feet)	Hardyston sandstone and quartzite (100-250 feet)			Antietam quartzite (150-300 ± feet)
				Harpers schist and Montalto quartzite member (2750 feet)				Harpers phyllite (1000-1500 ± feet)
				Weverton sandstone (1250 feet)				Chickies quartzite (800-1000 feet.) Hellam conglomerate (150-800 feet)

CHAPTER IV.

CAMBRO-ORDOVICIAN LIMESTONES.

DIVISION INTO FORMATIONS.

The most extensive limestone series of the State belongs to the Cambrian and Ordovician systems. Until recently the evidence for separating the Cambrian and Ordovician rocks in Pennsylvania was lacking, because the Cambrian and the Lower and Middle Ordovician are almost entirely composed of limestone and in most places in Pennsylvania fossils are few in both systems.

The geologists of the First Geological Survey of Pennsylvania put all these limestones into a single group called the No. II or Auroral series. The members of the Second Geological Survey designated the limestones as the No. II series although recognizing that it included the Calciferous, Chazy, and Trenton formations of New York where differentiations were more readily made. In 1892 the U. S. Geological Survey adopted the name "Shenandoah limestone" for the series, the name that is still used where sufficiently detailed work to permit differentiation has not been done. The geologists of the New Jersey Geological Survey have used the term "Kittatinny" to designate the same strata.

In recent years the series has been carefully studied in several places and divided into a number of different formations as shown by the accompanying diagram.

As shown in these sections the Cambro-Ordovician limestone series varies greatly in thickness in different parts of the State, the recent estimates ranging from less than 4,000 to more than 11,000 feet and some of the earlier as low as 2,000 feet. The characteristics also change from place to place so that the stratigraphic units or formations of one section may not be easily recognized in another section. However, these limestones are so familiar that a general description is more or less applicable to all of them.

TOPOGRAPHY OF LIMESTONE AREAS.

The Cambro-Ordovician limestones of Pennsylvania, because of their great thickness and their easy solubility compared with the rocks both above and below, are the most important valley-forming rocks of the State. The best example of this is the Great Valley that extends across the State, with a southwesterly trend, from New Jersey to Maryland and contains the thriving cities of Easton, Bethlehem, Allentown, Reading, Lebanon, Steelton, Carlisle, Chambersburg, and scores of smaller towns and villages. In New Jersey this valley is designated the Kittatinny Valley; between the Schuylkill and Susquehanna rivers it is known as the Lebanon Valley; and southwestward from the Susquehanna River it is called the Cumberland Valley. In Maryland and Virginia it is known as the Shenandoah Valley.

The widest valley floored by the Cambro-Ordovician limestones is the rich and fertile Lancaster Valley which comprises fully one-half of Lancaster County. An extension of this valley through York and into Adams County is known as the York Valley. In it are the important cities of York and Hanover. The beautiful Chester Valley that extends from Montgomery County southwestward through Chester and Lancaster counties is narrower than the others mentioned but no less famous. It includes the towns of Conshohocken, Downingtown, Coatesville, Quarryville, and many others. In the central and south-central parts of the State a number of Cambro-Ordovician limestone valleys have their best development in Clinton, Centre, Blair, Huntingdon, and Bedford counties.

Everywhere in the State the Cambro-Ordovician valleys are rich agriculturally on account of the fertility of the soils and the ease with which they can be cultivated. All of the larger, more continuous ones have afforded easy routes for railroads and for this reason many of the towns and cities located in these valleys have become important manufacturing centers.

The origin of limestone valleys has been briefly described in Chapter I of this report but it may be advisable to describe in greater detail the way in which the valleys of the Cambro-Ordovician limestones have been formed. All of them are found in that portion of the State lying southeast of the Allegheny Front, that is, in the region where the rock strata have been thrown into great folds, anticlines (upward folds) and synclines (downward folds). Immediately after the folding, provided erosion did not keep pace with the folding, the anticlines formed the ridges and the synclines the valleys regardless of the kind of rocks exposed at the surface. In time, however, erosion lowered both the former valleys and also the former ridges to a base level which was not far from sea level, below which the streams could not cut and carry away the resulting debris. The region was then a featureless low-lying plain, termed a peneplain, with nothing to distinguish the former locations of the hills and valleys nor the distribution of the harder (more resistant) and the softer (less resistant) rock strata.

At a later period the entire State of Pennsylvania and surrounding regions were uplifted, erosion was revived, and the streams reinvigorated sufficiently to carry away the disintegrated portions of the rocks. When this occurred the places where limestone strata were exposed were lowered more rapidly than the less soluble rocks and they have ever since remained as valleys.

Although the Cambro-Ordovician valleys are such prominent topographic features throughout the southeastern and south-central portions of the State they are not followed by the major streams. The larger streams had established their southeasterly courses before the uplift that followed peneplanation and with few exceptions they maintained their old channels. Thus nearly all the larger streams with prevailing southeasterly courses cut across these limestone valleys that, in general, have a northeast-southwest trend. Minor streams occupy the limestone valleys but they are not particularly conspicuous because so much of the drainage of these valleys is by means of subterranean channels, as described in Chapter I.

STRUCTURAL CHARACTER.

As stated above, the Cambro-Ordovician limestones of Pennsylvania are all within the region of folded strata. They were folded at the close of the Ordovician period and again at the close of the Permo-Carboniferous period. In the Great Valley and other valleys lying to the southeast the folding was intense and in many places the beds were broken and displaced. In these sections complex folds and faults are so numerous that it is not possible to determine the actual structure except along streams where there are continuous exposures. It is difficult to trace any one bed from outcrop to outcrop and consequently no one has been able thus far to estimate the thickness of these limestones with any fair degree of certainty. The figures of thickness given in the table are admittedly mere approximations.

The Cambro-Ordovician limestones in the central part of the State have likewise been folded and faulted but to a considerably less degree. Even there strata are found with the individual beds vertical or even overturned but the complexity gradually decreases westward to the Allegheny Front and the structural features can be more readily determined.

As would be expected the amount of jointing present in these limestones varies. In many places the joints are so numerous and so close together that it is impossible to obtain blocks for structural purposes. A short distance northwest of Lancaster a steam shovel has been operated in a limestone quarry without any previous blasting of the rock. Almost everywhere in the State the Cambro-Ordovician limestones are closely jointed, yet on the other hand there are numerous localities where good building material is obtainable. The beds that have been most folded and faulted naturally contain more joints.

LITHOLOGIC CHARACTER.

The Cambro-Ordovician limestones of Pennsylvania exhibit practically all the variations in lithologic features that are found in limestones. We find thick massive beds and thin shaly beds; limestone conglomerates, limestone breccia, edgewise conglomerates, oolitic and occasionally pisolitic limestones; blue, gray, white, buff, and almost black limestones; limestones with so large a proportion of sand grains that it is optional whether they be called arenaceous limestones or calcareous sandstones, and limestones that grade into shales by the large admixture of mud; hard, compact limestones and porous cavernous ones, and in one place near Annville unconsolidated calcareous material that resembles finely pulverized limestone; ripple-marked, sun-cracked, and rain-pitted limestones and those in which there are no evidences of shallow water deposition; and limestones in which chert nodules and siliceous concretions are abundant.

Of special importance is the variation in the metamorphism or marmorization of the Cambro-Ordovician limestones of the State. Commonly a certain amount of crystallization is evident but in many places the stone has been transformed into excellent marble. In general the best marbles of these periods are found in the closely folded strata southeast of the Great Valley but locally in other places the metamorphism has been sufficient to convert the limestone into marble.

PALEONTOLOGIC CHARACTER.

Throughout the State the Cambro-Ordovician limestones are characterized by the paucity of fossils. This is particularly true of the limestones of the Great Valley and regions lying to the southeast. Fossils are somewhat less rare in the central and south-central portions of the State but are markedly deficient in comparison with beds of similar age in New York and elsewhere. The Ordovician members contain more fossils than the Cambrian and in certain restricted localities certain layers are well-filled with crinoid stems, brachiopods, bryozoa, trilobites, mollusca, etc. The general scarcity of fossils together with the complicated structure has made the stratigraphic study of these limestones very difficult.

CHEMICAL COMPOSITION.

Any generalization concerning the chemical composition of the Cambro-Ordovician limestones might be misleading. The most common characteristic is their extreme variability in the quantity of each of the ordinary constituents of limestones.

The greatest variation is in the quantity of magnesium carbonate. This ranges from a fraction of 1 per cent to 48 per cent, exceeding the quantity present in the theoretical composition of dolomite.

The lower strata (Cambrian) almost everywhere are highly magnesian and the upper (Ordovician) beds less so, yet one finds occasional low magnesian limestones in the lower members and also high magnesian beds in the upper strata. Active search has been made in these limestones for dolomites for use in open hearth furnaces and for low-magnesian beds for cement and chemical uses. The efforts expended in both directions have been rewarded.

A. S. McCreath, chemist of the Second Geological Survey, made a most careful study of these limestones along the right bank of the Susquehanna River opposite Harrisburg. His results are given in Report MM, pp. 311-361. The range of $MgCO_3$ was from 0.5 per cent to 39.75 per cent. His conclusions were as follows:—

"1. Taking 115 beds, with a total thickness of 371 feet, from the lower middle part of the great magnesian limestone formation No. II—the "Calciferous Sandstone" of New York, and probably of Siluro-Cambrian age—and subjecting them individually to chemical analysis, they are seen to belong to two marked lithological species; one, a limestone, carrying 2 or 3 per cent of magnesia carbonate and 1 or 2 per cent of insoluble materials; the other, a dolomitic limestone, charged with from 25 to 35 per cent of magnesia carbonate and an average of over 7 per cent of insoluble matter, rising in some cases to 10 and 15 per cent or even more.

"2. These two species alternate, not in the same bed, but in separate beds, sharply distinguished from each other and traceable across the exposure, a distance of from 80 to 100 feet.

"3. The planes of separation are in most cases those of ordinary deposition.

"4. No current or cross or false bedding is visible.

"5. Some of the beds of both species are only a few inches thick; others are 6 or 8 feet thick; and there seems to be no rule connecting either species with the thin or with the thick beds.

"6. Sometimes a bed of limestone only 5 or 6 inches thick crosses the exposure between two equally thin beds of dolomite; yet there is no appearance of gradation in the deposits, nor in their chemical composition. The same percentages of carbonate of magnesia are found at both extremities of the exposure.

"7. In a few cases there is a decided difference in the amount of magnesia at one or other end of the exposure; but whether this be due to some error in the investigation, or to a radical change of composition along the bed which exhibits it, is not certain.

"8. There are thick masses of limestone strata with comparatively thin magnesian layers in their midst; and vice versa, there is sometimes a considerable thickness of magnesian rock parted by thin layers of nearly pure limestone.

"9. There are a few layers of an intermediate species; but these are not numerous enough to destroy the remarkable and sudden contrasts of alternate layers of limestone with 2 or 3 per cent of magnesia and layers with 25, 30, 35 or more per cent. In fact the extreme limits are often directly and repeatedly in contact with each other.

"10. The largest percentage of silica and alumina is almost invariably found in the high magnesian layers."

Analyses of the material obtained in a test drilling at Steuben's Switch, Northampton County, about 5 miles north of Bethlehem, show the same type of variation. The strata penetrated by the drill belong to the Beekmantown formation and are folded in a highly complex manner. Individual beds are sufficiently low in magnesium carbonate to permit their use for cement but others are practically pure dolomites.

Analyses of sections of Beekmantown limestone drill core near Steubens Switch, Northampton County.

[R. K. Meade, Analyst]

Depth in feet	Silica	Oxides of iron and alumina	Carbonate of lime	Carbonate of magnesia
0- 5	2.16	0.84	95.09	2.01
5- 10	5.46	2.10	58.27	33.10
10- 15	5.54	2.32	63.21	26.02
15- 20	5.94	2.92	64.13	25.26
20- 25	5.66	2.32	58.99	31.15
25- 30	5.96	2.14	79.52	11.68
30- 35	5.44	2.10	79.36	11.80
35- 40	5.36	2.14	79.70	11.35
40- 45	12.60	5.68	76.03	5.61
45- 50	6.56	2.10	85.56	5.05
50- 55	6.50	1.90	78.42	13.02
55- 60	4.26	1.74	76.41	16.14
60- 65	5.66	2.42	78.23	12.12
65- 70	4.44	1.80	81.35	11.57
70- 75	4.34	1.46	84.83	8.12
75- 80	-----	2.00	86.29	10.20
80- 85	21.74	7.92	61.01	8.02
85- 90	30.42	11.60	47.62	9.35
90- 95	10.60	3.88	52.60	31.12
95-100	7.34	3.68	53.85	33.23
100-105	9.74	4.28	56.07	27.40
105-110	10.26	4.52	78.78	4.44

Certain members of the Cambro-Ordovician limestone series contain considerable aluminous material, so that rocks grade between limestone and shale. The shaly layers are always high in silica. In many places the siliceous and aluminous matter has been metamorphosed to sericite (called *damourite* by the geologists of the Second Geological Survey of Pennsylvania). In Northampton, Lehigh and Berks counties, the uppermost member of the Ordovician limestones, the Jacksonburg formation, is highly argillaceous and low in magnesian carbonate. It is the best stone in the State for the manufacture of Portland cement, for which purpose it has been extensively used. This formation is described in detail in a separate chapter on Portland cement.

The amount of silica varies likewise in the Cambro-Ordovician limestones. In places occasional beds composed almost entirely of silica constitute distinct sandstone layers. Nodules and even more or less continuous bands of black flint are present in many places. However, most of the silica present is in combination with alumina as aluminum silicates. In quarries worked for fluxing materials the presence of a highly siliceous bed, interstratified with those of low silica content, renders the whole deposit much less desirable.

Sulphur, phosphorus, manganese, and many other constituents are present in these limestones but in almost every case in negligible quantity.

USES.

The limestone industry of the State is largely based on the Cambro-Ordovician limestones. Low and even moderately high silica limestones, both high and low in their magnesian content, have been extensively quarried for fluxes. Nearly all the iron furnaces in the eastern half of the State have in the past obtained the major portion of their fluxing limestones from these strata but lately increasingly larger quantities have been brought in from other regions. In recent years careful search has been made in Pennsylvania for low-silica dolomites for open hearth use, and has been successful.

Most of the lime produced in the State is made from Cambro-Ordovician limestones and for this purpose both low and high magnesian materials have been employed.

These same limestones have furnished most of the crushed limestone for the highways of the State and considerable has been shipped to other states. In almost every case these limestones, except where very shaly, will meet the rigid specifications of the State Highway Department. Crushed stone for concrete, and ballast and pulverized stone for fertilizing and filler purposes have been obtained from these limestones.

Locally these strata can be utilized for the manufacture of Portland cement but in most places they contain too much magnesium carbonate. A narrow band of limestone low in argillaceous matter that extends continuously across Northampton County and part of Lehigh County and in a few places in Berks County has been extensively quarried for cement manufacture and some unusually pure limestone in the Lebanon district has supplied the high grade stone required by some of the cement companies of the State.

The Cambro-Ordovician limestones have furnished much less structural material than one might expect from their accessibility. Comparatively few quarries have been opened primarily for building stone. The principal reason for this is the close spacing of joints and the irregularity in thickness of the beds. Years ago some highly desirable marble was quarried in the Chester Valley and it is probable that other regions where the metamorphism has been severe might yield marble of good grade.

In Chester and Montgomery counties there are several quarries in strata of this age where low-silica dolomites have been obtained for the extraction of magnesium carbonate,

DESCRIPTION OF INDIVIDUAL AREAS.

In the description of the Cambro-Ordovician limestones of different regions it has seemed best to adopt a geographic arrangement although it is recognized that there are some objections to this. The grouping is as follows:—

1. Bucks County.
2. Montgomery and Chester counties.
3. Lancaster County.
4. York and Adams counties.
5. Northampton, Lehigh and Berks counties.
6. Lebanon and Dauphin counties.
7. Cumberland and Franklin counties.
8. Lycoming and Clinton counties.
9. Centre County.
10. Huntingdon and Blair counties.
11. Bedford County.
12. Mifflin County.
13. Fulton County.

BUCKS COUNTY.

The two areas of Cambro-Ordovician limestone in Bucks County belong to the Great Valley type, like that in Northampton County.

One area is in the extreme northeast corner of the county and extends southwestward from the Delaware River near Riegelsville in a narrow band averaging about one mile wide.

All limestones of this region seem to be of Cambrian age and belong to the Tomstown and Conococheague (Allentown) formations. They are dolomitic and in most places high in silica. Many shaly beds containing much aluminum silicate are interstratified with the more massive beds.

Formerly these limestones were quarried in a number of places for lime and flux but in recent years have only been worked in a few places for road metal. A small quantity of building stone has also been quarried. The Durham magnetite iron mines that were operated for many years are in an area of gneiss adjoining the limestone and the furnaces where the ore was reduced are nearby. All limestone used for flux came from this region. In one of these quarries a cave was discovered about 100 years ago in which were found a number of bones of Pleistocene mammals representing several species no longer inhabiting the region.

Limonite iron ore was mined in this valley in several places and one of these old pits has in recent years been worked for umber.

The second and somewhat larger limestone area extends from the Delaware River about two miles north of New Hope in a southwest direction to Furlong (Bushington) about three miles southeast of Doylestown. The area is about 10 miles long and averages about 1½ miles wide.

This band is surrounded by Triassic sediments and the limestones are brought to the surface by a fault with a displacement of not less than 11,000 feet. No doubt these limestones are distributed through other portions of the county but elsewhere are deeply covered with the thick Triassic shales and sandstones.

Numerous quarries have been opened in this region for stone to be burned for lime but in recent years the local industry has greatly declined. Considerable crushed stone has been made from these strata. In two places some of the limestone has been pulverized for agricultural uses or for asphalt filler.

The Cambro-Ordovician limestones of Bucks County are of no special importance. They will doubtless continue to be worked in a small way for agricultural lime and pulverized limestone, for crushed stone, and building stone for foundations.

Analyses of Bucks County limestone.

	1	2
$CaCO_3$	52.50	53.49
$MgCO_3$	42.11	40.32
SiO_2	3.60	5.53
Al_2O_3	0.65	----------
Fe_2O_3	1.10	----------

1. Quarry of William Ely, 2¼ miles northwest of New Hope and 1 mile west of river road. Analysis of composite sample by Delaware River Steel Co,

2. Quarry of Herbert Havens, Limeport, 2½ miles above New Hope, along river road. Average of 10 analyses of samples taken over entire quarries and analyzed by the Delaware River Steel Co., Chester. Pa.

These samples are believed to be from the lower portion of the Cambro-Ordovician limestones.

MONTGOMERY AND CHESTER COUNTIES.

Chester Valley.

The Cambro-Ordovician limestones of Montgomery and Chester counties occupy Chester Valley, one of the most conspicuous and continuous topographic features of this portion of the State. The valley extends from near Willow Grove, Montgomery County, in a southwesterly direction almost 60 miles entirely across Chester County to Quarryville, in Lancaster County, where it joins the great Lancaster Valley. This valley has long been famous throughout the Philadelphia region for its natural beauty. It contains the towns of Plymouth Meeting, Conshohocken, Downingtown, Coatesville, Parkesburg, Pomeroy, Atglen and numerous small settlements. As far as Downingtown it averages about 2½ miles in width but from Coatesville to Quarryville it is almost everywhere less than one mile wide. The valley is normally bordered on the south by hills of mica schist and on the north by equally prominent hills of quartzite. Other types of rocks are in contact with these limestones in a few places. In almost every case the contiguous rocks are more resistant to erosion, hence they form the hills and the limestones underlie the valley. Geologic structure has brought some areas of other rocks within the valley but very few outliers of the limestones are exposed in the adjoining regions. Due to faulting there is a small detached area of these limestones in Huntingdon Valley extending from Bethayres to Somerton but so far as known the strata are everywhere covered by surface debris. These rocks have been found in excavations.

Character of limestone.—Chester Valley lies within that portion of the State where all of the rocks have undergone intense metamorphism, and the structures are complex. The limestones have been altered to marble and many new minerals were formed during the metamorphic process. The principal accessory minerals in these metamorphosed limestones are phlogopite, graphite, pyrite, siderite, and feldspar. The degree of metamorphism decreases from east to west.

Fossils have been found in only a very few places in the valley and consequently the exact correlation of the strata has not been determined. In the Philadelphia folio[21] and also in the unpublished geologic map of the Phoenixville quadrangle, F. Bascom has not attempted any division of these limestones but groups them all under the head of Shenandoah limestone. In the Quarryville district Stose and Jonas designate the strata there present as the Conestoga limestone which they regard as probably of Chazy age. Near Henderson Station some poorly preserved fossils have been found that seem to belong to the Lower Ordovician (Beekmantown). In our present state of knowledge it is necessary to consider all of the limestones of Chester Valley as a unit although recognizing the probability that eventually sufficient information may be obtained to warrant their division into several formations.

Dr. Bascom describes intercalated beds of siliceous or micaceous schists associated with these limestones, especially in the western part of Chester County. Near Pomeroy and Quarryville there is considerable conglomerate that Stose and Jonas regard as characteristic of the Conestoga limestone which they describe as "made up of thin-bedded dark slaty limestone, coarse conglomerate or breccia of limestone and marble pebbles and fragments, thin-bedded blue crystalline limestone, and thin, dark graphite slate." Both blue and white limestones are common and are interbedded. The white varieties are more coarsely crystalline. Calcite and quartz veins are abundant in most of the limestone of the valley but this is not universal.

Solution cavities are numerous and when filled with clay are decidedly objectionable. At Port Kennedy, near Valley Forge, a cave discovered in a quarry yielded a number of bones of Pleistocene mammals. Several limonite iron ore deposits occupying solution pits in the limestone were worked many years ago. Commonly the limestones are covered with several feet of residual clay, in places so thick as to make it unduly expensive to open a quarry.

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[21] U. S. Geol. Survey Geol. Atlas, Philadelphia folio (No. 162), 1909.

The limestones of Chester Valley show wide variations in their physical and chemical properties and have been extensively quarried for a variety of applications.

Marble.

At one time there was an important marble quarrying industry in Chester Valley. Marble from this region was in great demand in Philadelphia and surrounding regions. It was used in the construction of Girard College, the U. S. Custom House in Philadelphia, and other prominent buildings. The Washington sarcophagi at Mt. Vernon, and the Pennsylvania marble blocks in the Washington Monument are made of Chester Valley marble.

At Marble Hall, about 3 miles northeast of Conshohocken, there are three abandoned marble quarries. In the Journal of the Franklin Institute of Sept. 1867, Theodore D. Rand gives the following description of one of these quarries.

"About three-quarters of a mile west of Barren Hill, at Marble Hall, is the remarkable quarry of D. O. Hitner, Esq. This bed of marble, an altered Auroral or Trenton limestone, devoid of fossils, is nearly perpendicular, dipping S. 20°, E. 85°. The quarry itself is about sixty feet wide at the top, probably four hundred feet long and nearly or quite three hundred feet deep. The average thickness of the bed of white marble, which is of very fine quality, is about eight feet, but in one place it widens to twenty. Near the bottom of the quarry the bed of marble bends almost horizontally to the south-southeast, some fifteen or twenty feet, then again resumes its original direction. A few arches of the marble have been left to prevent the falling of the overhanging side of this vast and dangerous-looking chasm. Whatever the pleasure with which one may explore its depths, there is a great feeling of relief on safely emerging from it. A remarkable feature of this quarry is, that, although so deep and in limestone rock, very little water occurs; a comparatively small pump keeps it always dry enough for convenient quarrying.

"Except the marble, this quarry produces little of note to the mineralogist. Some twenty years ago a mass was detached and the usual hoisting apparatus applied, which gave way. It was repaired but again the same result followed, when it was found that the mass was far heavier than the marble which they had supposed it to be, and from which it could not be told by the eye—it was sulphate of baryta or heavy spar, the specific gravity of which (4.3 to 4.7) is nearly double that of marble (2.5 to 2.7), so that while a cubic yard of the latter would weigh about 4200 pounds, the same bulk of the former would weigh over 7500."

One of the Marble Hall quarries yielded a dark blue marble of good quality. If one may judge from the pile of refuse about the pits there was not much loss. The stone in the blue marble quarry shows some close folding.

Shainline's quarry at Henderson, and Henderson's quarry one-half mile south, have both yielded a fair grade of marble similar to the Marble Hall stone and may represent the same horizon. In the Lukens and Yerkas quarry, one-third mile southeast of Henderson there is a band of marble present but it is quarried, along with the other beds, for flux.

A quarry three-fourths of a mile southeast of King of Prussia was until recently worked for marble and yielded light gray and dark blue stones that were used for monuments and ornamental purposes. The sawing and polishing mills have now been dismantled and the entire output of the quarry is used for flux.

Although the Marble Hall, Henderson, and King of Prussia localities are the most prominent localities where marble has been quarried in the valley it is highly probable that other places exist where equally desirable marbles might be obtained. At present it is generally believed that the region cannot successfully compete with the marble districts of other States.

Dolomite.

More of these limestones have been quarried for lime than for any other purpose. Most of the quarries are small, were worked for local use, and are now idle. In recent years a number of large lime plants have been built in the region. These are mostly in the vicinity of Plymouth Meeting, Bridgeport, Port Kennedy, Howellville, Devault and Mill Lane.

Several different kinds of stone were formerly worked in the valley but at present little attention is given to any other than the low-silica dolomites. These are used for lime, flux, crushed stone, and in a few places for the extraction of magnesium carbonate. The rock is broken to secure blocks 10 to 12 inches in diameter (one man size) that are used for lime; the next size smaller is suitable for flux, and the fragments under 2 or 3 inches are used for concrete and ballast. When the demand for any one kind is particularly good, special efforts are made to produce as much of the desired size as possible. Generally it is not profitable to produce the smaller sizes.

The various companies operating in the region have made detailed investigations to find desirable quarry locations. The obstacles encountered are heavy overburden of clay and rotten rock, interbedded strata of high-silica content, clay seams or pockets, and contorted or shattered stone. For profitable operation the stone must be near the railroad and the topographic situation such as to permit ready operation and easy drainage. A number of quarries have been abandoned because of encountering one or more undesirable conditions.

A band of good stone seems to extend continuously from Shainline south of Bridgeport, north of Ivy Rock, through Plymouth Meeting, Corson's Station, to Williams. Good quarry stone has not been found continuously throughout the area but enough good quarries have been opened to make it seem probable that the band is continuous. At Shainline the stone has been quarried mainly for flux. South of Bridgeport are large quarries of the Merion Lime and Stone Co. and the Charles Warner Co. The former has two quarries, the Rambo and the Merion. The latter was idle at the time of our visit as much of the stone broke into sizes too small for the lime kilns and the demand for flux was very light at that time. The quarry is irregular in shape as some spots of poor stone were encountered. A strike of N. 85° W. with a dip of 55° SW. was determined. The Rambo quarry of the Merion Lime and Stone Co. and the McCoy quarry of the Charles Warner Co. are operating on the same beds. The rock is mainly a dense light-colored crystalline dolomite, although some bluish beds are present. The bedding planes are not distinct but it seems that the beds dip about 45° to the south with an almost east-west strike. There are numerous joint planes and in certain parts of the quarry the rock is badly shattered. The rock breaks irregularly when blasted and most of the blocks are small enough to be loaded at once or can be easily broken by sledges. The stripping averages 8 to 10 feet but is much deeper in occasional clay pockets. Most of the stone from these quarries is burned for lime but considerable is sold for open hearth dolomite. The lime is sold as lump lime to the building trade or hydrated and sold for agricultural uses. Some is furnished to glass and leather manufacturers.

Plymouth Meeting.—In the vicinity of Plymouth Meeting a number of quarries have been opened, most of which have long been abandoned. In the same section there are some old limonite iron ore pits. The chief reason for abandoning the quarries has been the presence of certain impure beds high in silica, alumina or iron. Also the overburden has been excessive in places. Nearly all of the stone has been used for lime. The quarry of G. & W. H. Corson is typical of the best quarries. (Plate III, A). The stone is a dolomitic marble with beds ranging in thickness from 6 to 40 inches and dipping to the southeast at angles of 50° to 55°. The strike averages about N. 75° E. The metamorphism has developed considerable sericite and muscovite. One streak of high-silica rock runs through the quarry. Very few veins are present. Most of the stone is burned and marketed as hydrated lime although some has been sold for flux and a small

A. Quarry of G. & W. H. Corson, Plymouth Meeting.

B. Bethlehem Steel Company quarry, Naginey, Mifflin County.

quantity used on the roads. Nearby is a quarry that was worked for a time by the Johns-Mansville Co. to obtain stone for the extraction of magnesium carbonate.

Half a mile west of Plymouth Meeting is the quarry and plant of the American Magnesia and Covering Co. The rock quarried is a high grade dolomite that contains from 45 to 48 per cent magnesium carbonate, 0.75 to 1.50 per cent silica, alumina, and iron oxide, the balance calcium carbonate. The stone is used for the extraction of magnesium carbonate, the process of which has been described in Chapter I of this report. The best stone is about 60 feet thick and is a gray to dove colored, compact, brittle stone. Another good variety is distinctly mottled. A blue stone underlying the best beds is also utilized except where it contains less than 40 per cent of magnesium carbonate. Only the blocks from 8 to 12 inches in diameter are used. The smaller sizes obtained in quarrying are used for concrete and road ballast.

Port Kennedy.—In the vicinity of Port Kennedy there has long been extensive limestone quarrying, but at present the largest quarries are idle. One of them is of interest as it shows the contact between the Triassic red shales and the Ordovician (?) limestone. This is the quarry where mammalian remains of Pleistocene age were found in a deposit of cave earth. The Ehret Magnesia Manufacturing Co. has its plant and quarry about 1¼ miles southwest of Port Kennedy. Their stone is a blue, gray, or white dolomite that averages about 45 per cent magnesium carbonate and less than 2 per cent impurities. The quarry is an old one but has been worked by the present company for about 18 years. The sizes less than 8 inches in diameter are sold for flux or for road ballast.

Near King of Prussia is the old Schweyer quarry long operated for marble but now owned and worked by H. E. Millard for fluxing stone. The quarry is very large and deep.

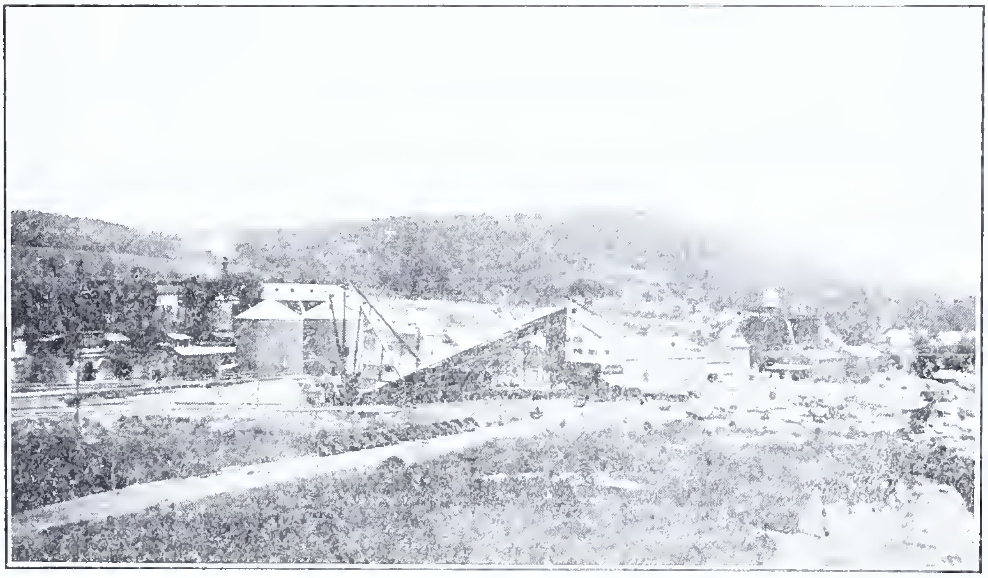
Just above Conshohocken on both sides of the river some impure limestones have been quarried in several places for the construction of railroad bridges, foundations for large buildings, and for walls.

At Howellville quarrying has been active for many years, most of the products being crushed for road metal or for concrete although good building blocks have also been produced. Quarries are now being operated there by E. J. Lavino and Samuel Gibbons. The Lavino quarry is said to have been in continuous operation for more than 35 years. It contains massive blue and white limestone with one shaly band. The beds dip to the southeast at an angle of 73° and strike N. 78°E. The massive beds contain few joints or veins. In

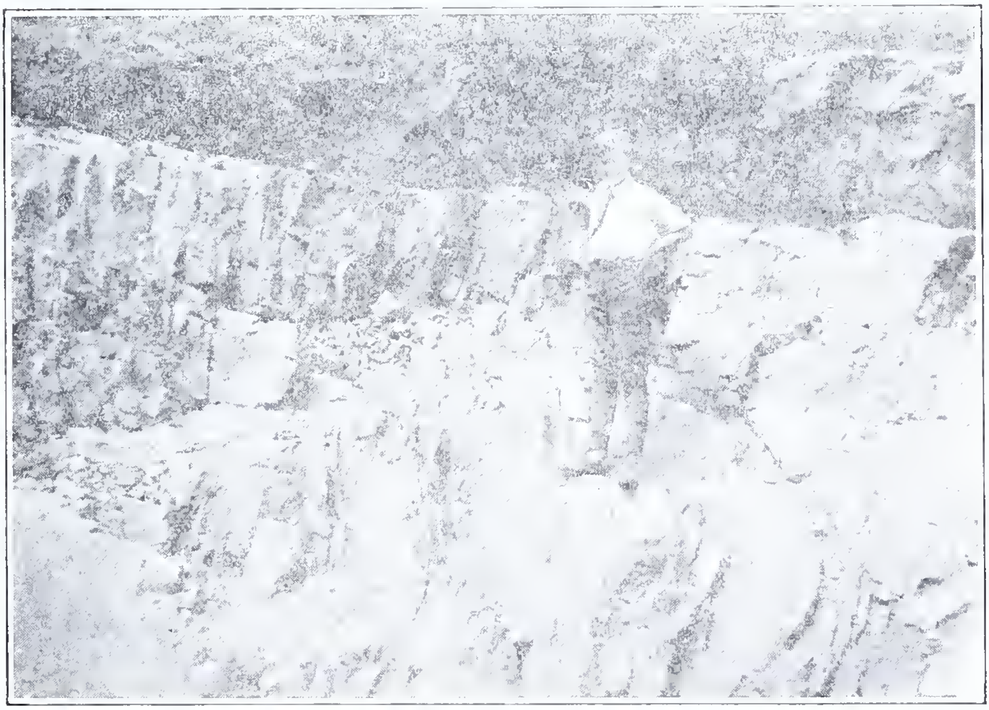
1921 the company was producing about 3,000 tons of road metal a week. They have sold some stone for flux and have ground some for agricultural purposes.

Cedar Hollow.—Half a mile southeast of Devault are the Cedar Hollow quarries of the Charles Warner Co. and one quarry of the Knickerbocker Lime Company. The rock is a low-silica dolomite. The beds dip from 45° to 55° S. with an approximate east-west strike. There are two bands of good stone, the northerly one with a surface outcrop about 1000 feet wide and the southerly one about 150 feet wide. They are separated by a band of high-silica stone that is not used. When the Charles Warner Co. connect all of their workings as planned they will have a continuous opening almost one mile long. The company burns the one-man size (10 to 12 inches in diameter) blocks in upright kilns. The undersize goes to a crusher where it is reduced to $\frac{3}{4}$ inch size. This size is burned in a rotary kiln and the finest is pulverized and sold as ground agricultural limestone. Charles Warner Co. plant at Cedar Hollow is shown in Plate IV, A.

The product of the Cedar Hollow quarry (No. 5) of the Knickerbocker Lime Co. is hauled over a branch railroad line to the main plant of the company along Valley Creek at Mill Lane. The company has worked quarries at a number of places along both sides of Valley Creek. On the north side there is almost a continuous opening for more than a mile in the same beds. Their No. 4 quarry on the southeast side of the creek is in the same strike. Another quarry (No. 6) known as the Holland Meadows quarry, lies about one mile to the northeast and is in a different series of beds. In the main series the beds quarried consist of low-silica dolomite and approximate 100 feet in thickness. They have a variable but always steep dip to the south. Some good stone is still being quarried here but in most of the openings it is no longer practicable to work the good grade of stone and their high grade lime is made principally from the stone brought from the Cedar Hollow quarry. Some of the poorer grade stone of the old quarries is being worked for road metal.



A. Charles Warner Co. plant, Cedar Hollow, Chester County.



B. Unconformity between Conestoga and Kinzers limestones at Kinzers, Lancaster County.

Analyses of Cambro-Ordovician limestone, Montgomery County.

	1	2	3	4	5	6	7	8
$CaCO_3$	55.62	55.80	58.29	55.72	55.56	56.19	52.98	55.78
$MgCO_3$	43.40	41.22	37.93	40.96	42.07	41.03	37.30	40.03
SiO_2	0.90	1.10	1.71	1.48	1.72	1.12	5.72	2.11
Al_2O_3 } Fe_2O_3	0.63	1.83	2.04	1.80	0.61	1.59	3.96	2.05

	9	10	11	12	13	14	15	16
$CaCO_3$	55.23	56.32	55.00	55.03	76.02	86.10	53.89	52.67
$MgCO_3$	43.22	41.95	43.19	38.50	18.17	11.86	42.72	45.46
SiO_2	0.65	0.75	0.41	2.36	2.52	1.33	2.14	1.20
Al_2O_3 } Fe_2O_3	0.92	0.96	1.54	4.09	3.23	0.68	1.24	0.58

1. Quarry of Blue Bell Lime Co., Williams. Analysis of 2 cars shipped Bethlehem Steel Co.
2. Quarry of G. & W. H. Corson, Williams.
3. Quarry of Cox Lime and Stone Co. 1 mile east of Plymouth Meeting.
4. Quarry of Joseph Leedom, Plymouth Meeting.
5. Quarry of American Magnesia Co., ¾ mile west of Plymouth Meeting.
6. Quarry of E. J. Lavino & Co., 1 mile west of Plymouth Meeting.
7. Quarry of Derr Crushed Stone Co., ½ mile north of Ivy Rock.
8. Quarry of Lukens & Yerkas, Mogee.
9. Rambo quarry of Merion Lime and Stone Co., Bridgeport. Analysis of 22 cars shipped to Bethlehem Steel Co.
10. Merion quarry of Merion Lime and Stone Co., Bridgeport.
11. Quarry of Pennsylvania Lime Products Co., Shainline.
12. Quarry of Norristown City Brick Co., Shainline.
13. Quarry of Lukens & Yerkas, ¼ mile S. E. of Henderson.
14. Quarry of H. E. Millard, ½ mile S. E. of King of Prussia.
15. Quarry of Erwin Stone Co., Port Kennedy.
16. Quarry of Ehret Magnesia Manufacturing Co., 1½ miles S. W. of Port Kennedy. Analysis furnished by company.

Analysies 1-15 were made by Bethlehem Steel Co.

Analyses of Cambro-Ordovician limestone, Chester County.

	17	18	19	20	21	22a	22b
$CaCO_3$	72.07–54.37	52.13	55.01	55.18–54.91	54.27–55.01–54.13	54.01	54.01
$MgCO_3$	22.01–35.94	44.26	42.96	42.32–41.90	42.69–42.32–43.03	42.69	42.54
SiO_2	3.96– 5.80	1.53	1.50	1.58– 2.12	1.78– 1.72– 1.51	0.85	1.63
Al_2O_3 } Fe_2O_3	0.70– 3.84	1.82	0.72	1.00– 1.12	0.82– 0.80– 1.27	0.44	0.57

17. Quarry of E. J. Lavino & Co., Howellville. Howellville blue stone. Stone used for road metal. Analyses by company.
18. No. 6 (Holland's Meadow) quarry of Knickerbocker Lime Co., 1½ miles northeast of Mill Lane. Analysis by company.
19. No. 3 quarry of Knickerbocker Lime Co., 1 mile east of Mill Lane. Analysis by company.
20. West end of quarry No. 1, Knickerbocker Lime Co., Mill Lane. Analyses by company.
21. Knickerbocker Lime Co's Cedar Hollow quarry, ½ mile S. E. of Devault. Analyses by company.
22. Quarries of Charles Warner Co. at Cedar Hollow, ½ mile S. E. of Devault. a. Quarry No. 6, average of 10 analyses. b. Whiteland quarry. Analyses by company.

LANCASTER COUNTY.

Lancaster County has a greater area of exposed limestone than any other county of Pennsylvania, and all the limestones belong to the Cambro-Ordovician series. They form a practically continuous, broad, east-west band that traverses the central part of the county, and constitutes the surface rocks of one-half the county. The fertility of the residual soils formed by the decay of these limestones is especially high and has won for Lancaster County the enviable position of the richest agricultural county of the United States.

As in other sections of the State the relatively soluble limestones underlie the valleys. The higher ridges in the northern and southern portions of the county are composed of sandstones, shales, schists, gneisses, trap, and other varieties of resistant rocks.

Division into Formations.

Until recently the limestones of the Lancaster Valley had not been differentiated although the paleontological work of Professor Roddy of Millersville State Normal School had proved the existence of both Cambrian and Ordovician strata. Stose and Jonas[22] have proposed the classification of the limestones given in the following table.

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[22] Jour. Washington Acad. Sci., Vol. 12, pp. 358-366, 1922.

Generalized columnar table.

Age	Name	Thickness (feet)	Character of rocks.
Ordovician	Conestoga limestone (probably older than, or in part equivalent to, Cocalico shale.)	500±	Dark slaty limestone, coarse limestone and marble conglomerate, thin-bedded granular blue limestone, and thin graphitic slate. Contains brachiopods and crinoid plates and stems of probably Chazy age. Overlaps southeastward on all formations from the Ledger dolomite to the Harpers schist.
	Cocalico shale.	1000±	Dark gray shale containing graptolites of Normanskill type and thin crinoidal limestone at base; gray, green, and purple slates and green impure sandstone above.
	Beekmantown limestone.	2000±	Light blue limestone and some light gray magnesian limestone and dolomite, containing a little chert. Carries Beekmantown fossils.
Upper Cambrian	Conococheague limestone.	900±	Massive blue limestone containing Cryptozoon reefs, thin-bedded wavy laminated limestones, sandstones and sandy conglomerates, and dolomite.
Middle Cambrian	Elbrook dolomite. Unconformity	500±	Cream-colored to white, fine-grained impure marble, mostly thinly laminated: weathers to shaly yellow tripoli and yellow earthy soil.
	Ledger dolomite.	1000±	Granular, gray to white dolomite, mostly thick-bedded, some beds of which are siliceous and weather to rust-stained granular cherty layers.
Lower Cambrian	Kinzers formation.	150	Siliceous banded dark blue limestone, impure dolomite weathering to dense buff tripoli, spotted white marble with wavy impure partings, and shale which contains an *Olenellus* fauna.
	Vintage dolomite.	500-650	Massive, glistening, coarse-grained, dark gray dolomite, weathering whitish with scattered crystalline blebs, and dark blue dolomite with argillaceous partings, weathering knotty or lenticular.

The Vintage, Kinzers, and Ledger are equivalent to the Tomstown dolomite.

The type section of the Vintage dolomite is exposed in a cut of the Pennsylvania Railroad at Vintage, a small village 15 miles east of Lancaster. The Kinzers formation is exposed in a railroad cut near Kinzers. The following section is given by Stose and Jonas.[23]

Partial section of Kinzers formation in railroad cut, Kinzers, Pa.

	Feet
Dark blue limestone with wavy impure partings	10
Thick-bedded light gray dolomite	12
Dark-blue limestone with wavy impure partings	6
White spotted marble with wavy buff dolomite partings	8
Blue limestone banded with slightly wavy siliceous layers	10
Highly siliceous banded dark limestone, weathering to skeleton of buff siliceous network	8
Impure thick-bedded dolomite, weathering to dense buff tripoli	3
White spotted marble with even buff dolomite banding	8
Wavy banded blue limestone, numerous argillaceous partings	10
Crumbly, fissile, dark shale, weathering spheroidal ..	50±
Impure dolomite, weathering to buff tripoli and containing few trilobite fragments and *Salterella*	7
	132±

The Ledger dolomite is named from the village of that name about 3 miles northeast of Kinzers. The Elbrook, Conococheague, and Beekmantown limestones are similar to the strata so designated by Stose in Cumberland and Franklin counties. The Cocalico shales, sandstones, and limestones and the Conestoga limestone are named from Cocalico and Conestoga creeks, Lancaster County.

The Conestoga limestone in the southern part of the limestone belt rests unconformably upon different members of the series in various parts of the county, thus indicating an uplift and an erosion interval between the deposition of the Beekmantown and the Conestoga limestones. At the Bellemont quarries the Conestoga rests upon the Vintage dolomite, north of Vintage it rests upon the Kinzers strata (see Plate IV, B), and in northeastern Lancaster it immediately overlies the Ledger dolomite.

The limestones and intercalated shales of Lancaster County have an aggregate thickness of about 6700± feet. They have been greatly folded and faulted and profoundly metamorphosed by the pressure and heat attendant upon the intense compression to which they have been subjected. In certain localities the limestones have been converted into marble and in almost every place they show some evidence of secondary crystallization.

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[23] Op. cit. p. 363.

The limestones are cavernous and much of the surface water finds its way into subterranean channels. Some of these underground streams eventually find an exit at the surface and form springs of very large size. The famous Lititz Spring is an illustration of this type.

At Leaman Place and in the northwest part of Lancaster an oil company has bored deep holes in the limestones in search of oil but without success.

Uses.

The limestones of Lancaster County have been quarried in almost every section of the limestone belt. In the Lancaster quadrangle Professor H. Justin Roddy has found 191 localities where limestone quarries have been opened. As this comprises less than one-third of the limestone area of the county it is probable that there are as many as 300 abandoned and working limestone quarries altogether. As in other sections of the State most of these quarries were small openings that furnished only a limited amount of stone for local use and have long since been abandoned.

Probably the earliest use of Lancaster County limestones was for building purposes. On the whole they are not well adapted for such use as there are few places where good building material can be obtained without an undue amount of waste. Most of the stone is closely jointed and the joints intersect at such angles as to require much work in dressing. The marble of the county is said to resist weathering poorly. However, some buildings are constructed entirely of local limestone and it has been generally used throughout the limestone belt for foundations.

For many years the farmers used lime freely for fertilizing the soil and many small quarries were opened to furnish the stone for the small local kilns. At present few farmers can afford to make the lime that they need because agricultural lime can be bought so cheaply, and the small farm kilns are now in ruins. In a few places, favorably situated for shipping, lime is still being burned and in large quantities. The largest operations are the J. E. Baker quarries at Billmeyer along the Susquehanna River and the Bellemont quarries southeast of Kinzers.

At Billmeyer three quarries are being operated. Two of them furnish a high calcium stone and the third, a short distance to the north, yields a low silica dolomite. Both the high calcium and the magnesian stone are burned for lime. When the plant was visited in 1921 the company had 51 ordinary upright kilns, 2 125-foot rotary kilns, 7 flame kilns, and 2 pot kilns. There is a hydrating plant here. The high calcium lime is used for soap and glass manufacture. Some of the high calcium stone is pulverized for use in the manufacture of plate glass, as an asphalt filler, and for agricultural uses.

A cement company was formed several years ago to make Portland cement from limestones one mile west of Brownstown. About 50 test holes averaging 100 feet in depth were bored and the results are reported to have been favorable. Three analyses are given on a later page. Only the stone of best grade was to have been used. Shale to be mixed with the limestone was to have been obtained about two-thirds of a mile to the northeast. On account of financial difficulties the plant was never erected.

The Mount Joy Magnesia Co. has opened a quarry along Big Chickies Creek, 3 miles south of Mount Joy where it is claimed that the company has found a low silica dolomite suitable for the extraction of magnesium carbonate. The plant and quarry were idle at the time of our visit as the company was in the hands of receivers.

Limestone and dolomite have been quarried for flux in several places. When the local iron ore mines of the region were in operation a number of furnaces were supplied with limestone from nearby quarries. Several quarries in the Marticville region were worked for flux to use in the nearby iron furnaces. Lancaster County limestone was also used to smelt the nickel ores that were long mined near Gap. With the closing of the iron mines and furnaces of the region the use of the local limestone for flux has diminished. The requirements for fluxing stone that can be shipped to compete with other limestones have increased so that now only the best quality stone can be regarded. The J. E. Baker Co. has shipped considerable low magnesian and high magnesian fluxing stone from their extensive quarries at Billmeyer and formerly quarried a dolomite near Bamford that was shipped for flux. The analyses that follow show that good fluxing stone occurs in several places in the county.

Since the development of macadam and concrete roads and concrete structures of all kinds there has been an excessive demand for crushed limestone and many abandoned quarries have been reopened and new ones have been developed. The Cambro-Ordovician limestones almost everywhere in the State possess the requisite qualifications and Lancaster County has supplied much crushed stone for use both within and without the county. Some of the localities where large quarries are worked for crushed stone are the following: one mile southeast of Columbia, 3 miles northwest of Lancaster, the Orchard quarry at Quarryville, and the Bellemont quarries southwest of Kinzers. There are scores of places where desirable stone for crushed stone can be obtained if the demand cannot be met by the present operations.

Analyses of Lancaster County limestones.

	1a	1b	2	3a	3b	3c	3d	4a	4b	5	6
$CaCO_3$	94.87	94.99	78.70	83.50	83.76	85.10	91.88	90.99	72.30	78.96	52.14
$MgCO_3$	2.63	3.35	17.71	14.36	13.15	12.92	5.89	6.60	19.85	--------	42.01
SiO_2	0.75	0.61	2.47	1.24	1.81	0.92	1.19	1.45	5.84	8.02	3.62
Al_2O_3 Fe_2O_3	1.09	0.54	0.99	0.81	0.95	0.75	0.51	0.61	1.93	1.63	1.92
S	0.015	0.015	--------	0.063	0.063	0.063	0.063	0.041	0.041	--------	--------
P	0.004	0.004	--------	0.008	0.008	0.008	0.038	0.006	0.006	--------	--------

	7	8a	8b	8c	8d	9	10	11	12	13a	13b
$CaCO_3$	55.88	54.750	55.104	53.517	50.339	54.51	54.63	54.93	55.01	55.07	72.11
$MgCO_3$	41.79	44.204	43.602	43.522	41.143	42.22	42.10	41.82	44.03	37.83	17.38
SiO_2	1.09	--------	--------	--------	--------	1.86	2.05	1.68	0.57	3.68	7.70
Al_2O_3 Fe_2O_3	0.98	.517	.304	.869	.731	1.35	1.32	1.09	0.67	1.41	2.72
S	0.006	.611	.023	.021	.030	--------	--------	--------	--------	--------	--------
P	0.006	.010	.016	.014	.029	--------	--------	--------	--------	--------	--------
Insoluble	--------	.436	.847	1.926	7.699	--------	--------	--------	--------	--------	--------

	14a	14b	14c	15	16	17	18	19	20	21	22a
$CaCo_3$	72.21	63.88	71.82	54.96	55.03	90.00	78.16	63.54	54.84	53.51	56.81
$MgCO_3$	20.29	--------	24.47	43.22	44.05	5.45	--------	24.87	42.84	41.08	40.23
SiO_2	5.36	14.54	3.20	0.49	0.33	2.54	7.91	8.47	1.03	3.52	--------
Al_2O_3 Fe_2O_3	1.84	5.18	1.04	0.65	0.68	0.81	5.82	2.81	1.24	1.85	2.24
S	--------	--------	--------	0.009	0.009	--------	--------	--------	--------	--------	--------
P	--------	--------	--------	0.008	0.008	--------	--------	--------	--------	--------	--------
Insoluble	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	0.40
H_2O	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	0.32

	22b	22c	22d	22e	22f	22g	22h	22i	22j	23a	23b
$CaCO_3$	53.29	53.28	53.17	53.19	68.22	86.24	88.67	83.46	90.89	74.46	91.97
$MgCO_3$	43.77	45.28	44.04	43.73	29.08	12.71	10.53	15.70	8.55	18.48	5.07
SiO_2	--------	--------	--------	--------	--------	--------	--------	--------	--------	3.24	2.36
Al_2O_3 Fe_2O_3	2.18	0.64	2.14	2.04	1.44	0.53	0.31	0.40	0.20	1.10	0.82
S	--------	--------	--------	--------	--------	--------	--------	--------	--------	0.018	0.018
P	--------	--------	--------	--------	--------	--------	--------	--------	--------	0.006	0.006
Insoluble	00.32	0.08	0.29	0.72	0.78	0.32	0.24	0.12	0.12	--------	--------
H^2O	0.44	0.72	0.36	0.32	0.48	0.20	0.25	0.32	0.24	--------	--------

1. Outcrops ⅜ mile west of Rheems on tract of J. A. Hipple. Average for phosphorus and sulphur.

2. Old Hipple quarries, ½ mile west of Rheems. Average analysis.

3. Quarry of J. A. Hipple, ½ mile S. W. of Rheems. Average for phosphorus and sulphur.

4. H. K. Landis quarry, 1¼ miles south of Rheems. Average for phosphorus and sulphur.

5. Abandoned quarry on Brobaker Farm, 1¼ miles North of Maytown.

6. Outcrop along left bank of a small stream, Rowenna P. O.

7. Hiestand quarry on east side of Donegal Creek, 1 mile from mouth. Average analysis.

8. Haldeman's quarries at Chickies.

a. South quarry, best blue limestone. Fine grained and very hard, brittle; light bluish gray, with irregular fracture.

b. North quarry, middle of quarry, best specimen. Rather coarse grained; hard and brittle; fracture irregular; light gray and brownish gray color.

c. North quarry, middle of quarry, worst specimen. Rather coarse grained, hard and tough; fracture irregular. Dark bluish gray.

d. North quarry, sandy layer at extreme north end of quarry. Specimen having the general appearance of a soft sand rock, is coarse grained and crumbling, brownish gray.

9. Outcrop on left bank of Big Chickies Creek, Heinaman farm, 1¼ mile N. E. of Chickies.

10. Outcrops on S. E. side of Chickies Creek, ⅜ mile from mouth.

11. Quarry on left bank of Chickies Creek at junction of Big and Little Chickies creeks.

12. J. E. Baker quarry on right bank of Big Chickies Creek just above junction with Little Chickies Creek.

13. Quarry west side of Little Chickies Creek. 2 miles S. of Mount Joy.

14. Outcrops and openings along left bank of Little Chickies Creek, 1½ to 1¾ miles south of Mount Joy.

15. Small quarry ¾ mile S. W. of Newtown, midway between railroad and Big Chickies Creek.

16. Outcrop at road crossing of Big Chickies Creek, ½ mile S. W. of Newtown.

17. Outcrop along left bank of Little Chickies Creek, near railroad, Mount Joy.

18. Quarry 2½ miles E. of Mount Joy on left bank of Big Chickies Creek.

19. Quarry ¼ mile S. of Centerville.

20. Outcrop on farm of Henry Musser, ¾ mile S. of Centerville.

21. Outcrop on farm of Chris. Musser, ½ mile S. of Centerville.

22. Strickler limestone quarries half a mile east of the intersection of Strickler Run and the Lancaster and Columbia (Pennsylvania) R. R. Analyses by J. B. Britton.

23. Stoner quarry at Pennsylvania R. R. crossing of Strickler's Run S. E. of Columbia. Average of three samples for phosphorus and sulphur.

	23c	23d	24	25a	25b	25c	26	27	28a	28b	28c
$CaCO_3$	56.03	69.13	93.91	92.53	90.81	86.89	94.23	53.93	52.28	51.23	74.42
$MgCO_3$	42.03	25.48	4.53	4.66	6.15	5.36	2.19	41.83	39.35	39.05	16.67
SiO_2	0.94	4.28	0.90				1.69	2.54			
Al_2O_3 / Fe_2O_3	1.23	1.25	0.56	0.84	1.18	2.40	0.59	1.65	4.51	2.88	1.51
S	0.018		0.047					0.010			
P	0.006		0.009					0.010			
Insoluble				1.61	1.38	4.03			3.38	3.42	7.12
H_2O				0.36	0.48	0.49			0.48	0.42	0.28

	28d	28e	28f	28g	28h	28i	28j	28k	29	30a	30b
$CaCO_3$	86.50	93.34	89.17	88.77	90.64	93.24	87.75	57.43	55.01	82.50	54.50
$MgCO_3$	11.15	4.39	4.51	5.75	4.14	3.56	5.16	24.73	42.85	15.88	42.91
SiO_2									1.40	1.08	1.49
Al_2O_3 / Fe_2O_3	0.54	0.29	0.44	0.64	0.58	0.40	0.44	3.36	0.76	0.58	0.85
S									0.037		
P									0.007		
Insoluble	1.45	1.62	5.60	4.52	4.08	2.28	6.25	13.96			
H_2O	0.36	0.36	0.28	0.32	0.56	0.52	0.20	0.52			

	30c	31	32	33a	33b	33c	34	35	36a	36b	36c
$CaCO_3$	61.64	51.03	97.25	65.95	81.48	98.31	67.08	91.49	52.06	55.42	55.35
$MgCO_3$	34.36	37.62	1.49	3.91	7.31	0.80	30.30	7.23		44.26	43.71
SiO_2	2.54	7.81	0.61	23.65	8.68	0.64	1.53	0.85	5.05	0.28	0.49
Al_2O_3 / Fe_2O_3	1.51	3.74	0.53	5.45	3.20	0.28	1.09	0.46	0.71	0.42	0.45
S									0.003	0.006	0.003
P									0.014	0.014	0.014

24. Old Strickler quarry, ¾ mile S. E. of Columbia.
25. Limestones 300 yards N. E. of the Strickler quarries. Analyses by J. B. Britton.
26. Quarry on Strickler Run ⅔ mile west of Glenmanor.
27. Quarry at Glenmanor.
28. Limestones about ½ to 1½ miles south of Manheim along track of P. & R. R. R. and near County Bridge. Analyses by J. B. Britton.
29. Large quarry between Lititz and Fruitville turnpikes, 1 mile N. of Lancaster. Average analysis.
30. H. H. Landis quarry, ½ mile S. E. of Landis Valley. Average for phosphorus and sulphur.
31. Outcrop, south of Ephrata turnpike, 1¼ miles E. of Landis Valley.
32. Outcrop on Weidler Farm near right bank of Cocalico Creek, 1 mile E. of Oregon.
33. Limestones from farm of Alvin Wenger, 1 mile W. of Brownstown. It was planned to use the No. 3 stone for the manufacture of Portland cement.
34. Outcrop on Minnich farm near abandoned railroad cut, 1 mile N. of Brownstown.
35. Quarry near left bank of Conestoga Creek 1 mile N. W. of Farmersville.
36. Bellemont quarries, east of Bellemont. Average for phosphorus and sulphur.

Analyses 1-5, 7, 10-21, 23, 24, 26, 27, 29-36 by Bethlehem Steel Co.

YORK AND ADAMS COUNTIES.

Limestone Valleys.

The limestones that form such a wide band through the central part of Lancaster County extend across the Susquehanna River into York County in two places. In the vicinity of New Holland (Saginaw P. O.) limestone in a triangular area, less than one square mile in extent, represents the same limestone strata exposed and quarried at Billmeyer, Lancaster County. The main band crosses the river at Wrightsville and continues in a southwesterly course entirely across York County and to Littlestown, Adams County, only a few miles from the Maryland-Pennsylvania line.

This more extensive band of limestones underlies and is responsible for the formation of York Valley in which are located the principal towns and industries of York and Adams counties. The valley averages about 1½ miles wide except in the vicinity of York and Hanover, in both of which places it is about 5 miles wide. The southern boundary is a fairly regular line with few indentations but the northern one is irregular. In the vicinity of York there is one off-shoot of the main valley that extends northwestward to Emigsville and another that extends westward a few miles beyond Thomasville. Both of these branch valleys owe their existence to folding and faulting by which limestone is brought to the surface.

On the north side of the limestone valley there are exposed either the underlying Chickies quartzite or the much more recent overlapping red shale and sandstone of Triassic age. The strata bounding the valley on the south are principally slate or schist, probably in the main of Ordovician age.

Until recently the limestones were believed to belong entirely to the Cambrian system, as Walcott and others had collected Cambrian fossils from various places within the valley. Stose and Jonas[23] now refer the limestone conglomerate and associated strata, so extensively developed in York County, to the Conestoga formation and state that they have found in them, east of York, some brachiopods and crinoid stems and plates that are regarded as of Chazy age. Their revised columnar section is given on a previous page under the discussion of the Lancaster County limestones.

The U. S. Geological Survey geologists who are studying these strata will doubtless be able to establish definite lines of separation between the different limestones present in the valley, but such data are not available at present and it is therefore necessary to discuss the limestones of York and Adams counties as a unit, as has been done in the past.

Character of Limestone.

The structural characters of the York Valley limestones are very complex, as is true of all of the limestone areas of southeastern Pennsylvania, and much detailed work is necessary before it is possible to do more than outline the most general features. In almost every quarry or extensive natural exposure there is evidence of intricate folding and faulting. The mantle of residual clay soil that covers the limestone almost everywhere along erosion channels and artificial excavations, prevents the acquisition of data that might make it possible to accurately determine the structures. To determine the structure it is necessary to prospect a limestone property either by extensive drilling or by digging trenches or pits.

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[23] "Lower Paleozoic section of Southwestern Pennsylvania," Jour. Wash. Acad. Sci., Vol. 12, pp. 358-366, 1922.

It seems that nearly all the folds are closely compressed and that the strata have a more or less prevailing steep dip to the southeast although there are many exceptions to this generalization.

The numerous varieties of limestone are practically all crystalline and many of them have been converted into beautiful medium to coarse-grained marbles. The degree of marmorization depends partly upon the amount of compression that the strata have undergone but more upon the original physical and chemical composition of the rocks. The massively bedded strata are much more crystalline than the thinly bedded ones and the purer limestones and dolomites are likewise more highly crystalline than are the argillaceous or arenaceous varieties. Many minerals characteristic of metamorphic calcareous rocks are present. Numerous vein minerals are also found in small quantity, most of them probably brought in by the heated circulating waters during the process of metamorphism. Jandorf[24] lists the following minerals that have been found in these limestones:

Graphite
Galena
Sphalerite
Chalcopyrite
Pyrite
Marcasite
Fluorite
Quartz
Hematite
Limonite
Calcite
Dolomite
Ankerite
Siderite
Aragonite
Malachite
Asbestos
Chlorite
Serpentine
Talc
Nitro-calcite
Barite
Gypsum

Conglomerate.—Almost every quarry of considerable size exposes a number of layers of stone possessing different physical as well as chemical characters. One of the most interesting phases is the conglomerate or breccia variety of the Conestoga formation that is well developed in the vicinity of York and extends eastward to Wrightsville and westward to Thomasville. This has been called "intra-formational conglomerate" and also "edgewise conglomerate." The latter term is appropriate only where the fragments are thin and are not parallel to the bedding planes. In some places the fragments and the cementing matrix are so nearly the same color and so similar in all other respects that a freshly broken piece of rock scarcely reveals the conglomeratic character but on exposure to the weather the matrix is dissolved more readily and the fragmental origin of the rock is strikingly exhibited. At the quarry of the York Valley Lime and Stone Co. near Hellam Station beautiful examples of this kind can be seen. Elsewhere the fragments are lighter or darker in color than the matrix and the fragmental character can be readily determined. The best examples of this stone observed were in the quarries of the Palmer Lime and Cement Co., southwest of York. The stone is there termed "calico rock" and two different types occur. One, known as "light calico," has angular and irregular fragments of a dull gray color enclosed by a matrix of white stone with both fragments and matrix well crystallized. Another variety, called "dark calico," contains dark bluish gray fragments in a muddy gray cement. In places this matrix contains an appreciable quantity of pyrite.

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[24] Jandorf, M. L., Preliminary report on the York Valley limestone belt: Pa. Top. and Geol. Survey Comm., 1910-1912, pp. 106-112, 1912.

The fragments of this conglomerate are of various sizes up to 3 feet in diameter. In some places the fragments are fairly uniform in size but, in general, large and small pieces are present in the same bed. Some are rounded as though they have been worn by being rolled but most are decidedly angular and seem to indicate ice transportation as suggested by Walcott. No explanation that has thus far been offered for conglomerates of this kind seems to account satisfactorily for the formation of these York Valley conglomerates.

Massive and thin beds of uniform color—white, gray and dark bluish gray to almost black—are also present, interbedded with the conglomerates. In some quarries, as for example the Bittinger quarry of the Bethlehem Steel Co. north of Hanover, the rock in portions of the quarry is so uniform that it is difficult to determine the bedding planes.

Thin shaly layers of little value for any purpose are present in some quarries and materially add to the difficulties and expense of operation.

In places an especially soluble layer has become porous or cavernous near the surface. The openings have a tendency to fill with clay washed down from the surface and then are objectionable. A 5-foot bed of this kind at the quarry of the Thomasville Stone and Lime Co. contains so much clay that it is difficult to keep the good stone clean.

Oolitic limestones are not abundant in the region but are found occasionally. The best example noted was at the quarry of the Thomasville Stone and Lime Co.

The York Valley contains a large quantity of unusually fine stone. It has yielded a great deal of low silica, dolomite and low silica and low magnesium so that much of the raw stone and the lime formed from it have been in demand for fluxes and for various chemical uses. In addition there are many high silica limestones and dolomites that are better than the low silica varieties for crushed stone and ballast.

Some of the quarry men have been fortunate in finding sufficiently large bodies of high grade stone of fairly uniform composition so that they have little difficulty in meeting the demands of their customers. Generally, however, due to complexity of structure and variations in chemical composition of the different beds, and even within the same bed, the operators must use unusual care in working their quarries in order to obtain a uniform product. The quarries worked for chemical limestone or lime must carefully avoid the spots where the stone is high in silica, alumina and pyrite whereas the quarries furnishing crushed stone must waste the shaly layers sometimes encountered.

For these reasons it is always well to put down a number of test drill holes before opening any quarry in the region unless the natural exposures are unusually good.

Variations.—No better example of variations in the stone can be given than the data obtained on the farm of S. Forry Laucks, 2 miles north of York where 10 core drill holes were put down to depths of 125 to 263 feet. The rock at that point as exposed in two small abandoned quarries is metamorphosed to such an extent that the bedding planes are indistinct. Except in a very general way and for the holes relatively close together it was not found possible to correlate the beds by either chemical or physical characters.

Sections and analyses of limestone from Laucks farm 2 miles north of York.

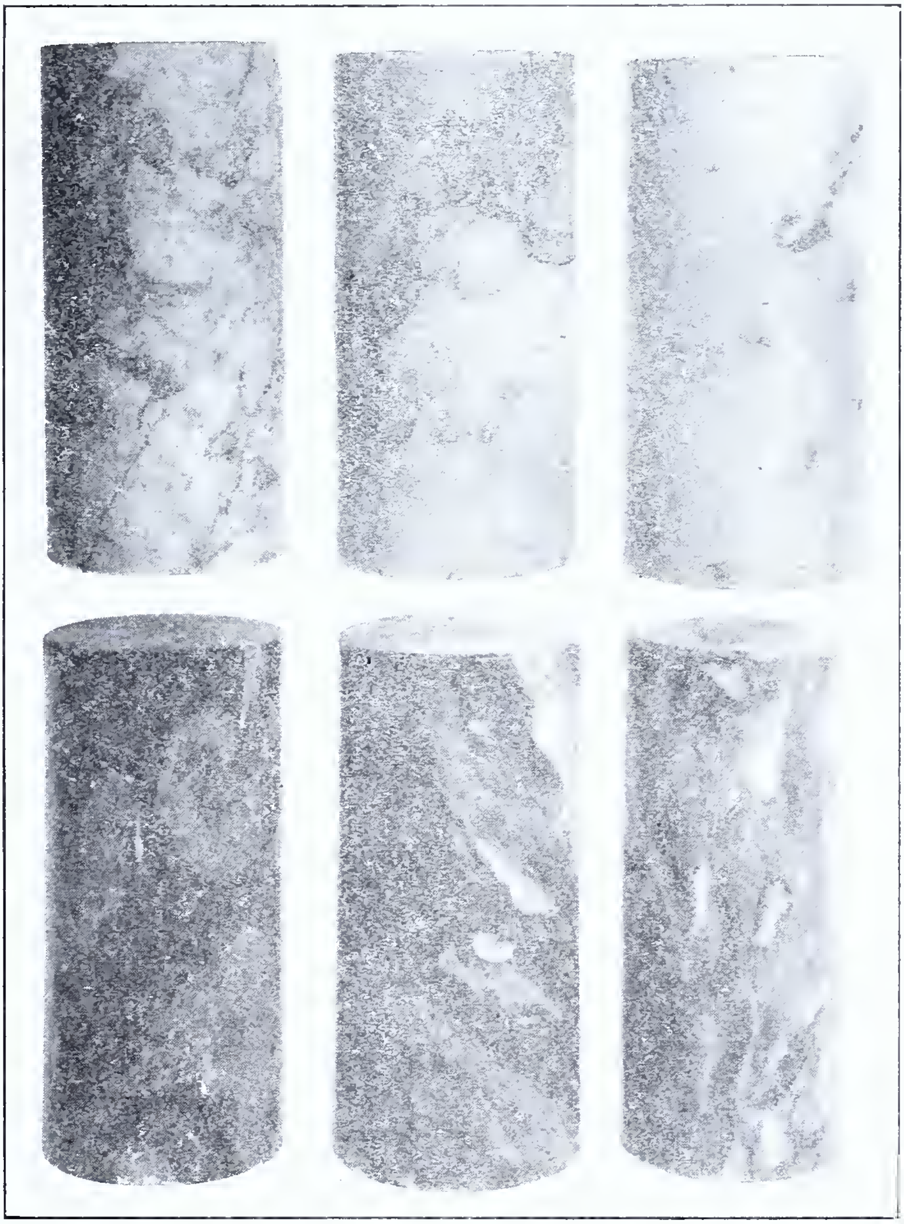
Hole No. 1.—261 feet	Feet	$CaCO_3$	$MgCO_3$	Al_2O_3 Fe_2O_3	SiO_2	P for entire hole
A. White dense crystalline stone	42	97.89	1.66	0.22	0.20	
B. Grayish blue stone	4	98.37	1.47	0.20	0.04	
C. Same as A	33	96.81	2.89	0.20	0.12	
D. Approximately dolomite	1	59.29	40.25	0.44	0.11	
E. White crystalline stone	33	96.87	2.76	0.15	0.25	
F. Light blue stone	18	95.72	3.97	0.20	0.17	
G. Light blue stone with pink discolorations	21	93.12	6.52	0.24	0.18	
H. Blue stone slightly darker than G	68	91.92	6.30	0.55	1.24	
I. Dark blue stone	22	83.82	14.24	0.63	1.39	
J. Very dark blue stone, rather soft and graphitic	19	75.44	21.87	0.93	1.84	0.004
Hole No. 2.—217 feet Overburden 2-feet						
A. White crystalline stone	18	97.95	1.83	0.08	0.11	
B. Dense crystalline gray stone 2′						
Gray stone 0′8″						
Gray stone 0′6″						
Gray stone 1′10″	5	62.45	36.79	0.38	0.34	
C. White Stone 11′						
White stone 1′						
Dense white crystalline stone 53′ with pinkish tints in spots and turning grayish towards lower 20′	65	96.89	2.83	0.31	0.17	
D. Dense grayish white stone	71	96.14	3.13	0.27	0.12	
E. Darker gray stone	44	85.76	12.46	0.50	1.30	
F. Very dark blue stone graphitic	12	76.16	21.79	0.66	1.50	0.005
Hole No. 3—263 feet Overburden 2-feet						
A. White crystalline stone with small blue inclusions	128	97.40	2.55	0.14	0.14	
B. Gray hard stone 4′						
Gray stone 3′	7	73.32	25.48	0.48	0.66	
C. White stone 3′						
White stone 10′	13	93.44	6.02	0.25	0.36	
D. Rather hard gray stone 57′						
Streaked with blue 4′	61	62.51	34.54	0.73	2.33	
E. Dense blue stone 25′						
Dense blue stone 27′	52	91.94	6.77	0.48	0.90	0.0045

Hole No. 4.—150 feet Overburden-7 feet	Feet	$CaCO_3$	$MgCO_3$	Al_2O_3 Fe_2O_3	SiO_2	P for entire hole
A. Dense white crystalline stone	79	96.55	3.06	0.19	0.22	
B. Blue stone	16	97.00	2.64	0.13	0.17	
C. Gray crystalline stone, dense but weathered in spots	48	73.11	25.90	0.76	0.11	0.0027
Hole No. 5.—125 feet Overburden-12 feet						
A. Dense white crystalline stone with pinkish tint	44	95.91	3.68	0.15	0.23	
B. Pinkish gray stone with streaks of dense white crystalline stone	30	62.67	36.51	0.56	0.13	
C. Dense gray stone	20	94.42	4.99	0.19	0.25	0.003
D. Siliceous, poor looking stone-19 feet						
Hole No. 6.—144 feet Overburden-9 feet						
A. White stone	6	97.54	2.05	0.16	0.20	
B. Gray crystalline stone	59	75.78	23.78	0.27	0.13	
C. Blue stone getting darker with depth,	65	93.80	5.89	0.44	0.92	
D. Dark blue stone	5	79.40	18.48	0.69	1.36	0.006
Hole No. 7.—106 feet Overburden-10 feet						
A. Dark blue graphitic stone slightly dolomitic	96	92.28	5.93	0.43	1.42	0.012
Hole No. 8.—247 feet						
A. Dolomitic stone in spots	17	86.95	10.95	0.44	1.66	
B. Dolomite 3′ Dolomite 0′6″	3½	55.66	43.03	0.64	0.74	
C. White stone 4′ White stone 70′6″	74½	96.04	2.90	0.24	0.78	
D. White stone siliceous in spots	52	88.43	3.22	0.20	8.22	
E. Dolomite	4	57.69	40.99	0.44	0.72	
. Light blue mottled stone	33	94.30	3.52	0.14	1.90	
G. Dolomite	18	55.70	43.30	0.43	0.58	
H. Rather poor looking dolomite	45	88.44	9.29	0.59	1.87	0.007
Hole No. 9.—227 feet Overburden-4 feet						
A. White crystalline stone	40	97.81	1.86	0.12	0.28	
B. Dolomite	6	63.84	33.96	0.71	1.48	
C. White stone with pinkish discoloration	65	97.96	1.75	0.10	0.27	
D. Dolomite	1	61.61	37.47	0.26	0.49	
E. Dense white stone with grayish streaks	45	97.24	2.31	0.13	0.40	
F. Grayish limestone	56	95.53	3.14	0.15	1.10	
G. Dolomite weathered	10	57.92	41.48	0.33	0.27	0.003
Hole No. 10.—147 feet Overburden-4 feet						
A. Hard dense dolomite	143	55.01	42.42	1.09	0.34	0.010

Uses.

The limestones of the York Valley have long been quarried and the limestone industry has passed through about the same stages described in the discussion of other regions. The earliest uses were for building purposes and for agricultural lime and numerous small openings were made to supply nearby local users. From 1850 to about 1885 the numerous limonite iron ore mines of the limestone valley and adjoining regions and some magnetite mines in the older crystalline rocks to the south were worked and the ores reduced in

PLATE V.



Polished drill cores of marble from Laucks farm, York.

the nearby region. Many limestone quarries were therefore opened to supply stone for flux. With the closing down of all these iron mines, the increase in cost of labor, and the improvement in railroad transportation, the small quarries were abandoned and large quarries were opened near the railroads and in localities where the quality of the stone was superior. These have been extensively worked for lime. The latest extensive use has been for crushed stone for roads and for concrete.

The limestones of York and Adams counties are not particularly well adapted for construction purposes although local stone was used for a number of buildings and still more has been used for foundations. The joint planes are numerous and irregular so that in most places it is difficult to get out building blocks without undue waste. These joint planes are due to the compression which the strata have undergone.

Dressed marble, so far as known, has never been taken from the York Valley, notwithstanding the fact that in several places north and west of York there are some beautiful varieties. Some of the cores obtained in diamond drilling on the farm of S. Forry Laucks, 2 miles north of York, have been polished and are unusually attractive (See Pl. V, p. 97). There is some pure white but most is handsomely mottled, particularly the conglomerate layers described on a preceding page. There are the light varieties and the darker shades and one gray and white with pink bands and blotches. Undoubtedly the marble would find a market for interior decoration. It would have to be quarried with channeling machines as the stone breaks too irregularly in blasting. On account of joints there might be a large amount of waste although at lower levels the joints would probably be less numerous. The high grade character of the stone, as shown by the analyses on a preceding page, would permit the utilization of the refuse for lime, flux, or other uses.

High-grade chemical lime is made at several places, most notably at the Thomasville quarries (See Plate VI), and those located west and southwest of York.

White cement is made 1 mile west of York by the Sandusky Cement Co. Formerly a limestone quarried adjacent to the plant was used but in recent years the stone has been obtained from the Thomasville quarries. The white clay mixed with the limestone is obtained from Cumberland and Huntingdon counties.

Fluxing stone is now quarried extensively in the vicinity of Bittinger but many of the other quarries primarily worked for lime have stone that would be highly desirable for flux.

The demand for crushed stone has been so great during the past few years that many quarries have been worked entirely for this product. These are mainly near Hanover, York and Wrightsville.

A. Quarry of Thomasville Stone & Lime Co., York County.

B. Heavy blast in Thomasville quarry.

Space will not permit a separate description of each quarry but a few districts are worthy of special attention. In the 1910-1912 Report of the Topographic and Geological Survey Commission of Pennsylvania M. L. Jandorf has given a somewhat detailed description of 16 quarries between Wrightsville and Hanover.

Bittinger.—The region around Bittinger, about 2½ miles northwest of Hanover, contains a number of quarries most of which are now idle. The largest now in operation are those belonging to the Bethlehem Mines Corporation and the Steacy-Wilton Co. The former is rapidly developing into the largest quarry of the district. The equipment for quarrying is elaborate, consisting of a drag line excavator to remove the overlying clay which averages about 6 feet in thickness, a 4-cubic yard steam shovel, cable haulage and rock house, large gyratory crusher, trommels, etc.

Several varieties of stone occur in the quarry. There is a white crystalline marble that is almost pure calcite, a dark bluish-black stone that is also high in calcite, and a pinkish gray gnarly dolomitic stone. The relations of these varieties to each other is indeterminable on account of the crushed character of the beds. Numerous slickensided rocks can be found throughout the quarry. The north part of the quarry is mainly in the dolomite and the east and southeast faces show high calcium stone. The solution cavities beneath the clay cover are deeper and more irregular in the low magnesian rock than in the dolomitic varieties. This quarry is worked primarily for flux for the blast furnaces at Sparrows Point, Md., although the material from the crusher, less than 2 inches in size and some larger, is sold for road use.

Adjoining the quarry of the Bethlehem Mines Corporation is the quarry of the Steacy-Wilton Co. that is worked primarily for stone to be burned for lime. The stone in the two quarries is similar except that the quantity of the dolomitic variety is smaller in the latter. In certain places the bedding planes can be clearly distinguished. They dip steeply to the northwest. Several faults are also recognizable although the amount of displacement cannot be determined.

Thomasville.—The Thomasville region contains some of the very best stone in the district. The quarry of the Thomasville Stone and Lime Co. is the largest in York County and covers several acres. The quarry face is approximately 1200 feet long. The beds are almost horizontal, an unusual feature for the region. On the west side of the quarry near the top there is a dolomitic layer with a pinkish tint but the remainder of the quarry with a working face 50 to 60 feet high contains high-calcium, low-silica stone. A large part of the rock consists of limestone conglomerate or breccia. In 1920 the company quarried 191,665 tons. Of this 74,912 tons were sold for blast furnace use, 48,487 tons for open hearth flux, 10,018 tons burned for lime, 19,279 tons pulverized for glass and other chemical manufactures, and 8,969 tons of screenings for road use. The stone burned made 22,863 tons of lime of which 19,475 tons were sold as bulk lime, 346 tons of pulverized lime, and 3,042 tons of glass and agricultural lime. The combined kilns, 14 in all, have a capacity of about 125 tons a day. The equipment of the plant is described in a recent number of Rock Products (Vol. XXV, No. 7, Apr. 7, 1923.)

The J. E. Baker Co. has recently opened a quarry of similar rock on adjoining land and is burning lime. There are several small abandoned quarries nearby.

York.—Of the quarries close to York, the Palmer Lime and Cement Co. is one of the best. It contains several varieties of stone varying in physical character as well as in percentage of magnesium and silica. Unusual care must be exercised in working the quarry to avoid mixing the different grades. The dark and light "calico" conglomerates described on a previous page are especially abundant. Parts of the quarry show some very close folding but throughout most of the quarry the metamorphism has been so intense as to obliterate the bedding planes and the structures are indeterminate. The company burns practically all of the stone quarried and markets it as lump, pulverized, and hydrated lime. A large quantity is used for chemical purposes and also for agriculture. The capacity of the plant with ordinary draft is 300 tons of lime per day or 360 tons with forced draft. Part of the stone quarried is a very handsome mottled marble and might be utilized for interior decoration. So far as known it has never been used in this way.

The York Stone and Supply Co. operates a quarry 1½ miles north of the center of York where they have a working face about 90 feet high in the side of a hill.

Section in York Stone & Supply Co. quarry, near York.

	Feet
Overburden of clay....................................	4
Compact crystalline rock with pinkish or light green tint	20
Dense dark blue to black rock..........................	50
Gray somewhat shaly rock exposed on southwest corner of quarry..	15

All the material is crushed and sold for concrete and for road and street work in the vicinity. The capacity of the plant is about 375 tons per day.

Several quarries in the vicinity of Hellam Station have been worked for lime in the past. At present the principal one of the these in operation, on the farm of Walter F. Myers, west of Hellam Station, is leased by the York Valley Lime and Stone Co., and worked entirely for crushed stone. It contains a 30-foot stratum of high calcium, low-silica rock that was formerly worked for high grade lime and also a 20-foot bed of low-silica dolomite. A shaly band of poor rock cuts through the quarry. The operations are mainly confined to a series of grayish-blue compact massive beds exposed in the north part of the quarry.

At Stoner's Station stone has been quarried for lime in a small way and efforts have recently been made by the Wrightsville Stone and Lime Co. to expand the operations.

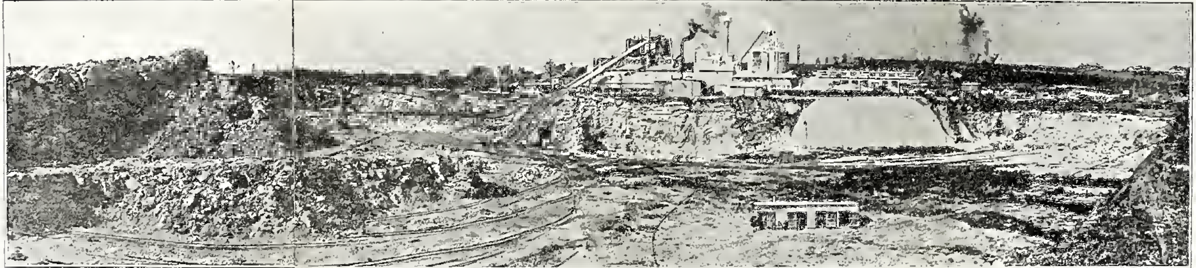
Section in face of quarry at Stoner's Station.

	Feet
Limestone conglomerate	11
Thin to thick beds of limestone	25
Shaly limestone	2
Limestone breccia	8
Shaly limestone	2
Extremely coarse limestone conglomerate	12
Shaly layer	3
Limestone conglomerate	8
Shaly conglomerate exposed in bottom	

Two old quarries at Wrightsville have furnished a great amount of stone for lime in the past. One of these, belonging to the Beard Lime Co., was closed a few years ago when an extensive landslide occurred, and the other one owned by the Steacy-Wilton Co., will probably be closed soon as the operations have extended almost to the property lines. When visited in 1921 it was being worked for crushed stone and supplying about 100 tons per day. The dip and strike were determined at a place that seemed to represent a fair average of the prevailing inclinations and found to be: strike N.80°-W., dip 55° S. W. There are several varieties of rock in the quarry, some of which are shaly and of little use. A layer of impure limestone about 4 feet thick has been quarried for building purposes. Conglomerate layers are common throughout the quarry. In some of them the individual fragments are 10 to 12 inches in diameter.

At New Holland (Saginaw P. O.) the J. E. Baker Co. is working a bed of low-silica dolomite about 60 feet thick for stone for flux and for lime that is sold for plaster, agricultural and chemical purposes, and an underlying bed of low-silica, high-calcium rock, about 55 feet thick, that is sold for flux and for road metal. The structure is fairly regular, the beds dipping about 15°N. From the quarry northward to the Triassic contact there are numerous exposures of limestone that is said to be a low-silica dolomite.

PLATE VII.



Palmer Lime & Cement Company lime plant and quarry, York.

Shows kilns at upper end of incline, hydrator at right, stone crusher at left, sacking and warehouse above waste dump, layout of tracks in quarry.

Chemical analyses of limestones of York and Adams Counties.

Adams County.

	1	2	3	4	5	6	7	8
$CaCO^3$	69.02	76.05	85.90	75.63	65.92	89.55	73.59	60.77
$MgCO_3$	21.39	1.03	11.64	17.35	27.10	2.86	20.62	34.01
SiO_2	7.35	21.90	1.65	5.08	5.01	6.16	4.42	4.37
Al_2O_3	1.19	0.20	0.17	1.08	0.99	0.63	0.39	1.03
Fe_2O_3	0.90	0.66	0.53	0.76	0.83	0.66	0.82	0.74
S	0.012	Trace	Trace	Trace	0.00	0.014	0.00	0.00
P	0.014	0.009	Trace	0.008	0.023	0.009	0.004	0.12

	9	10	11	12a	12b	12c	12d
$CaCO^3$	54.68	52.58	69.93	67.95	75.82	98.19	51.70
$MgCO_3$	42.58	40.00	25.10	28.88	20.22	0.20	46.80
SiO_2	1.80	5.41	3.93	1.85	1.51	0.60	0.60
Al_2O_3	0.06	1.20	0.43	0.25	0.24	0.08	Trace
Fe_2O_3	0.79	0.70	0.53	0.79	0.62	0.77	0.66
S	0.013	0.00	Trace	0.052	----------	----------	----------
P	0.007	0.014	0.008	0.007	----------	----------	----------

1. Two old pits on farm of A. J. Bair, 3 miles southwest of McSherrystown. Average of 2 samples.
2. Old pit on farm of A. Grove, 2 miles southwest of McSherrystown.
3. Abandoned quarry on farm of Andrew Rudisville, 1 mile west of Bittinger.
4. Small pits on farm of John Krug, 1 mile west of Bittinger. Average of 5 analyses.
5. Small opening on farm of John Krug, 3 miles northwest of Hanover, ¾ mile north of Bittinger. Average of 2 samples.
6. Abandoned Slagel Quarry 2¾ miles northwest of Hanover.
7. Jacob Moul Quarry, 2½ miles northwest of Hanover. Average of 6 samples.
8. 2 abandoned quarries on farm of Clayton Berkheimer, 2½ miles northwest of Hanover. Average of 4 samples.
9. Outcrop on farm of J. H. Barnett, 2¼ miles northwest of Hanover.
10. Abandoned quarry of George Slagel, 2⅓ miles northwest of Hanover.
11. Steacy-Wilton Quarry 2¼ miles northwest of Hanover. Average of 82 samples.
12. Bittinger Quarry of Bethlehem Steel Co., 2¼ miles northwest of Hanover. a. Average analysis of 136 samples; b. Average analysis of 15 samples; c. High calcium stone; d. High magnesium stone.

York County.

	13	14	15	16	17	18	19	20	21	22	23
$CaCO_3$	87.39	88.78	53.02	67.36	53.09	54.25	60.67	80.64	77.16	90.00	75 01
$MgCO_3$	8.11	9.95	37.80	11.01	40.09	41.84	22.86	14.00	18.27	6.03	19.95
SiO_2	3.60	0.80	1.10	14.87	4.36	2.00	12.88	4.27	3.48	2.81	3.30
Al_2O_3	0.25	Trace	0.73	4.09	1.57	1.00	2.29	0.22	0.35	0.08	0.34
Fe_2O_3	0.57	0.35	7.17	1.98	0.88	7.75	1.28	0.85	0.85	0.45	0.99
S	Trace	Trace	0.00	0.00	0.00	Trace	0.004	0.02	0.015	0.024	0.020
P	0.017	0.012	0.030	0.097	0.100	0.115	0.034	0.018	0.028	0.023	0.016

13. Abandoned quarry on farm of Wm. Keffer, 1½ miles north of Hanover. Average of 2 samples.
14. Small quarry on farm of Samuel Witmer, 1¼ miles north of Hanover.
15. Outcrop along railroad at Jacob's Mill 3 miles northeast of Hanover.
16. 2 small quarries on farm of J. J. Hershey along R. R. 1 mile southwest of Menges Mills. Average of 2 samples.
17. Small abandoned quarry on Lewis farm a short distance northeast of Menges Mills, north side of R. R. Average of 2 samples.
18. George Hoke Quarry along Pennsylvania Railroad, a short distance northeast of Menges Mills.
19. Bittinger abandoned Spring Grove Quarry on P. R. R., ½ mile southwest of Spring Grove. Average of 6 samples.
20. J. B. Rebman abandoned quarry, 2 miles west of Thomasville. Average of 2 samples.
21. 3 abandoned quarries of King and Williams, 1 mile west of Thomasville. Average of 6 samples.
22. Old quarry belonging to Paul Krugg, 1 mile west of Thomasville. Average of 2 samples.
23. Spengler abandoned quarry, ½ mile west of Thomasville.

York County—Continued.

	24a	24b	25	26	27	28	29	30	31	32	33a
$CaCO_3$	88.51	36.90	56.45	94.90	94.73	92.36	92.98	76.78	68.59	55.35	55.48
$MgCO_3$	10.87	42.30	30.30	18.75	4.26	5.43	4.99	14.37	26.68	42.65	42.56
SiO_2	0.27	0.30	1.58	2.26	0.78	1.75	1.53	7.65	3.85	1.00	0.89
Al^2O^3	0.06	0.04	0.33	0.08	Trace	0.35	0.62	0.33	0.11	Trace	0.44
Fe_2O_3	0.20	0.44	1.21	0.60	0.36	0.04	0.38	0.75	0.66	0.92	0.51
S	0.00	--------	0.020	0.020	0.00	0.00	Trace	0.00	Trace	Trace	0.066
P	0.00	--------	0.022	0.014	0.030	0.015	0.013	0.030	0.014	0.016	0.012

	33b	33c	33d	33e	33f	34a	34b	35	36a	36b	37a
$CaCO_3$	55.91	55.49	83.46	55.71	55.56	55.23	84.25	72.95	78.22	90.22	93.90
$MgCO_3$	42.38	42.68	11.08	37.64	38.48	42.90	12.87	24.50	20.04	5.85	5.27
SiO_2	0.71	1.11	4.79	5.18	2.46	0.81	1.90	1.17	0.96	3.29	
Al_2O_3	0.22	0.28	0.18	0.74	0.80	0.17	0.16	0.42	0.05	0.00	0.22
Fe_2O_3	0.69	0.55	0.56	0.81	0.75	0.78	0.63	0.88	0.51	0.57	
S	0.00	Trace	0.109	0.020	0.010	Trace	Trace	Trace	Trace	0.004	--------
P	0.008	0.010	0.018	0.012	0.017	0.020	0.020	0.038	0.018	0.020	--------

	37b	37c	38	39	40	41a	41b	41c	41d	42	43
$CaCO_3$	99.76	55.51	54.44	70.64	85.61	80.71	97.44	58.41	84.58	78.33	86.98
$MgCO_3$	Trace	41.60	41.10	25.80	4.86	9.63	1.66	36.77	11.21	14.87	2.17
SiO_2			3.70	1.40	7.65	7.61	0.40	0.91	2.88	5.63	9.21
Al^2O^3	0.06	1.20	0.00	0.66	0.83	1.04	0.10	3.83	1.28	0.36	0.72
Fe_2O_3		--------	0.88	0.64	1.16	0.90			--------	0.80	0.84
S	--------	--------	0.00	Trace	Trace	Trace	--------	--------	--------	0.024	0.010
P	--------	--------	0.024	0.022	0.008	0.010	--------	--------	--------	0.009	0.024

24. Quarry of Thomasville Stone and Lime Co., ½ mile southwest of Thomasville. a. Average of 7 samples of low magnesium stone, b. High magnesium stone.

25. Farm of Robert Baer, 1 mile east of Thomasville.

26. 3 abandoned Gross quarries, 1¼ miles east of Thomasville. Average of 14 samples.

27. Farm of Wm. Yost, 1½ miles east of Thomasville. Average of 6 samples.

28. Farm of Jacob Emig, 1½ miles east of Thomasville. Average of 9 samples.

29. Farm of Zach. Louver, 2 miles east of Thomasville. Average of 3 samples.

30. Farm of Wm. Yost, 2 miles east of Thomasville. Average of 4 samples.

31. Farm of Wm. Bott, 2¾ miles west of York. Average of 10 samples.

32. Farm of Gise & Diehl, 2 miles west of York.

33. Wm. Smyser Farm, purchased by Bethlehem Steel Co., 2 miles west of York. Averages of 6 100-foot holes with analysis every 5 feet. a, b, and c located in east part of property, d, e, and f in west and northwest part.

34. David Bentzel Farm, 2 miles west of York. a. average of 4 samples. b. average of 3 samples.

35. Farm of Theo. Helb, 2 miles west of York.

36. Farm of Chas. Kurtz, 1½ miles west of York. a. Average of 2 samples. b. Average of 3 samples.

37. Palmer Lime and Cement Co., 1½ miles southwest of York. a. White and mottled (calico) marble. b. Pure white sugary marble. c. Gray dolomite. Analysis by company.

38. Property of C. M. Eichelburger, 1 mile west of York.

39. Quarry of Emigsville Limestone Co., Emigsville. Average of 7 samples.

40. Abandoned quarry of East York Co., 1½ miles east of York. Average of 3 samples.

41. York Valley Lime and Stone Co., (farm of W. F. Myers) ¾ mile west of Hellam Station. a. Average of 14 samples. Analyzed by Bethlehem Steel Co. b. 30-foot bed extensively worked for lime. c. 20-foot bed of low silica dolomite. d. Fair average of run of quarry exclusive of shaly layers. Analyses b, c, and d furnished by Company.

42. Benjamin Stoner quarry, ⅔ mile northwest of Hellam Station. Average of 10 samples.

43. Quarry of John Emig, southeast of Hellam Station. Average of 5 samples.

York County—Concluded.

	44a	44b	44c	44d	44e	44f	44g	44h	44i
$CaCO_3$	93.49	64.99	95.47	92.64	94.17	87.52	86.00	94.24	98.04
$MgCO_3$	2.61	6.40	2.53	2.22	4.45	9.29	4.75	2.51	1.86
Insoluble	4.05	26.07	2.26	5.19	1.65	3.17	8.30	2.50	0.82

	45	46a	46b
$CaCO_3$	61.15	56.05	92.70
$MgCO_3$	33.55	42.00	5.00
SiO_2	3.43	1.10	1.25
Al_2O_3	0.26	0.85	1.05
Fe_2O_3	0.59		
S	0.006		
P	0.034		

44. Property of Wrightsville Stone and Lime Co., Stoner's Station. a. Conglomerate in quarry; b. Shaly layers in quarry; c. In woods near railroad; d. Conglomerate near kiln; e. Outcrop in field east of quarry; f. Near railroad bridge; g. Lowest grade conglomerate in quarry; h. Dark stone near kiln; i. Best stone from main conglomerate layer in quarry. Analyses by J. W. Kellogg.

45. Quarry of Beard Lime Co., Wrightsville. Average of 10 samples.

46. Union Stone Co., New Holland. a. Average analysis of 55-foot bed of low silica dolomite. b. Average analysis of 90-foot bed of high calcium stone. Analyses furnished by Company.

Analyses 1-36, 38-40, 42 and 45 made by Bethlehem Steel Co.

NORTHAMPTON, LEHIGH, AND BERKS COUNTIES.

The Cambrian and Ordovician limestones of the Great Valley and its off-shoots lie within the counties of Northampton, Lehigh, Berks, Lebanon, Dauphin, Cumberland, and Franklin. For purposes of discussion these are treated in this report in three divisions. The first division, the area comprised within Northampton, Lehigh and Berks Counties, lies almost entirely between the Delaware and Schuylkill rivers; the second division including Lebanon and Dauphin counties is between the Schuylkill and Susquehanna rivers; and the third division of Cumberland and Franklin counties is between the Susquehanna River and the Maryland border.

The limestones of Northampton, Lehigh, and Berks counties form a continuous band from four to eight miles wide occupying the central portions of these counties and trending from northeast to southwest. In addition to the main body, there are in each of the three counties some partially and wholly detached smaller areas resulting from folding and faulting of the strata and subsequent erosion. As a consequence of similar complexities of structure there are some small outliers of both older and younger non-calcareous rocks within the limestone areas.

The limestones of this belt are bordered on the south and southeast by the higher ridges known variously as South Mountain, Lehigh Mountain, or Durham and Reading Hills. These ridges composed of the resistant Cambrian sandstones and quartzites and pre-Cambrian gneisses, rise to a height of 900 to 1100 feet above sea level. The limestones in the adjacent valley have an elevation of 200 to 500 feet. On the north and northwest the limestones are in contact with the younger shales and slates of the Martinsburg (Hudson River) formation. These are more resistant to erosion than the limestones and therefore the summits of the slate hills are considerably higher, rising to elevations of more than 800 feet in many places.

The limestones of this belt have been divided into several formations as shown in the following table, although the area has not yet been completely mapped.

Classification of the Cambro-Ordovician limestones of Northampton, Lehigh and Berks counties.

			Thickness in feet.
ORDOVICIAN.		Martinsburg shales and slates overlying the limestones.	
	Shenandoah (Kittatinny) limestone	Jacksonburg low-magnesian argillaceous limestones extensively used in manufacture of Portland cement	250-600
CAMBRIAN.		Beekmantown limestone, normally high in magnesium carbonate	1,000±
		Conococheague (Allentown) dolomitic limestone	1,500±
		Tomstown dolomitic limestone	1,000±
		Hardyston sandstone and quartzite underlying the limestones	

In general it is possible to differentiate the limestone formations although there are some places where this cannot be done with certainty. All of the limestones were deposited in shallow water and exhibit the characteristics of such deposition,—ripple or wave marks, sun or mud cracks, rain drop prints, breccia and conglomerates, oolite, and frequent and rapid changes in physical and chemical composition both laterally and horizontally. They have also all undergone much metamorphism which probably destroyed many of the fossils, although it is not believed that these limestones ever were rich in organic remains except in restricted localities. Recrystallization of the carbonates is common and considerable sericite is present along the bedding planes. All the limestones contain numerous joints and calcite and quartz veins.

Tomstown Formation.

The Tomstown formation contains considerable interbedded shaly material that has a tendency to weather quickly so that good outcrops are seldom found. It also contains some massive-bedded compact layers normally dark blue in color. The limestone is everywhere high in magnesium carbonate and in many places quite siliceous. No fossils have been found in the formation. The Tomstown outcrops along the lower slope of the quartzite and gneiss hills except where faulting has placed other formations in this position. The thickness is approximately 1,000 feet. The Tomstown limestone has been quarried for lime, flux, crushed stone and in a few places for building purposes.

Conococheague Formation.

The Conococheague (locally designated Allentown) formation is the thickest and most prominent of this series of limestones. It is normally present near the center of the limestone valley although, due to folding and faulting, it may be found in other places. It can usually be recognized by the abundance of the fossil *Cryptozoön proliferum,* a form of calcareous algae that was graphically described by Lesley, former State Geologist, who did not recognize its true character, in the following sentence: "A very strange peculiar and entirely mysterious feature of some beds is a structure resembling a mass of clam shells closely packed together with their rounded sides uppermost." On the edges of the beds, they appear as a series of thin layers in symmetrical waves that vary from half an inch to more than a foot in width. On the upper surface they appear as small knobs or bumps from one-half to one inch in height.

The Conococheague limestones are everywhere high in magnesium carbonate, although there is considerable variation. Deep weathering gives a banded appearance to interbedded strata with different percentages of magnesium carbonate because the more highly dolomitic beds turn whiter than others. This is generally an excellent criterion for recognizing the formation, as the other formations of the region do not show this phenomenon well. Some layers are highly siliceous and in several localities there are a few thin interbedded sandstone layers. Shaly beds are present but not common. The best figures that have thus far been secured for the thickness of the Conococheague limestone approximate 1,500 feet.

The Conococheague has been quarried extensively for lime and crushed stone, less extensively for flux, and in a few places for building material.

Beekmantown Formation.

The Beekmantown formation is mainly confined to the northern or northwestern portion of the limestone belt. In places several species of molluscan fossils are present although, as a whole, organic remains are very scarce. The individual limestone beds are more heterogeneous than those of the underlying formations. This is not especially noticeable on fresh surfaces but is pronounced on weathered portions, producing an irregularly mottled appearance. Unlike the Tomstown and Conococheague formations, the Beekmantown contains occasional beds of low magnesian limestone that are suitable for the manufacture of Portland cement. No place is known, however, where the thickness of these layers is great enough for a quarry to be opened in them alone; consequently in quarrying it is necessary to sort the material carefully by hand and use the high magnesian stones for other purposes if material for cement is sought in the Beekmantown strata. The formation has an approximate thickness of 1,000 feet.

Jacksonburg Formation.

The uppermost limestone formation of this area is the Jacksonburg, more commonly known as the Cement Rock formation, because it has furnished such a large quantity of stone for making Portland cement. The formation has not been recognized throughout the entire region, thus indicating an unusual and somewhat local type of deposit. From the Delaware River opposite Belvidere it has been traced continuously through Stockertown, Nazareth, Bath, Jacksonville, and Siegfried to the Lehigh River and westward a few miles beyond Ironton. Disconnected areas occur in the vicinity of Fogelsville, Lehigh County, and Evansville, Berks County.

The Jacksonburg overlies the Beekmantown limestone and is overlain by the Martinsburg shales and slates. The width of the band exposed at the surface ranges from one-fourth to two miles depending upon the thickness and inclination of the beds.

The characteristics of the Jacksonburg limestone are discussed on pages 116-122 under Cement.

Martinsburg Formation.

A few lenses of limestone are present within the basal Martinsburg shales and have been quarried for lime in several places on a small scale. They are of minor importance.

Structure.

The structure of all the limestone strata of Northampton, Lehigh, and Berks counties is very complex. Folding and faulting have so greatly disturbed the strata that rarely can one find any considerable area in which the beds are even approximately horizontal. Simple folds and overturned folds, normal faults and thrust faults of minor and major degree have been observed in scores of places. Were it not for the surface soils that so generally conceal the strata our detailed maps would show many more faults and axes of folds than they now do. Correlation of beds and determination of exact thickness is impossible in most places. Both the folds and faults have a general trend from east to west or northeast to southwest but there are many transverse to these lines.

Joints and veins of calcite and quartz are common in all the limestone formations of the region and consequently good structural material is uncommon.

Quarry Economics.

Not uncommonly bluffs from 20 to 160 feet high rise above the streams. Railroads follow nearly all the major streams and some of the minor ones. The conditions favor limestone quarrying as a quarry face with good drainage can be easily developed and transportation facilities are close at hand. The over-burden of residual clay, rotten limestone, or glacial debris is seldom thick. It perhaps averages about 4 feet. Solution pits or pockets in the rock surface are common and are always filled with clay. Deep pits are a serious obstacle in working the quarry. Fissures filled with clay are also encountered in many quarries. Cavities or small caves containing "cave onyx" are not uncommon but in no place in the district have these cave deposits been of economic importance. In general the solution cavities of all kinds are most numerous where folding and the consequent shattering of the rocks have been most intense.

Uses.

The limestones of Northampton, Lehigh, and Berks counties have been quarried in scores, even hundreds of places. In the Allentown quadrangle that includes the major portion of the limestones of Northampton County and a small portion of Lehigh County 300 quarries have been opened. It is estimated that 500 to 600 have been operated in the three counties. Naturally most of them were small and were worked only for local use. With the industrial development of the district a number of large quarries have been opened in the vicinity of the railroads and are supplying a great quantity of stone for flux, lime and crushed stone for concrete and road building.

Flux.—The Tomstown, Conococheague, and Beekmantown limestones have been worked to supply fluxing material for the numerous iron furnaces that have been operated between Easton and Reading. Most of the furnaces were built when the iron mines of the region were in operation and have since been abandoned but, in a few places, especially the Bethlehem and Reading districts, the small furnaces have been replaced by large ones requiring far more flux and they in part still rely upon local quarries for their supply.

Although the limestones of the area are being used extensively it cannot be claimed for them that they are entirely satisfactory. The great advantage in their favor is their proximity to the furnaces. Considerable limestone of superior quality is shipped into the region from New Jersey and from Lebanon County. On the other hand the Parryville Iron Company at Parryville long obtained fluxing limestones from a quarry near Northampton and the New Jersey Zinc

Company operates a quarry at Allentown to obtain flux for use at its Palmerton plant.

The worst feature of the limestones of the area for flux is the presence of occasional sandy or shaly beds with a high percentage of silica. Solution cavities filled with clay are frequently encountered. These are more abundant than they would have been if the strata had not been so greatly shattered and deformed by earth movements. Deep solution pits or pockets filled with clay are numerous and make the removal of the overburden expensive. These rocks are so variable in character that careful sampling and usually core drilling are required to determine their availability for use for flux. Experience has shown that most properties so prospected have been rejected as undesirable.

The largest quarry now being operated in the region for limestone flux is owned by the Bethlehem Steel Company and is located immediately across the Lehigh River from the plant. The rock belongs to the Conococheague formation. The quarry is worked on a large scale and is well equipped in every respect. The product is taken from the quarry to the blast furnaces by an aerial tram. The same company obtains similar limestone near East Allentown and formerly operated a large quarry near Redington in the Tomstown formation. It was abandoned mainly because of the unsatisfactory character of the material.

Building stone.—The abundant limestone strata of these counties should contain good building stones in some places but no really good quarry is known. There are several reasons for this lack of good stone. Perhaps the chief reasons are the shattered character of the rock, the irregularity of the joint planes, the curvature of the beds and the presence of numerous veins of calcite and quartz, all of which are the result of the intense compression to which these rocks have been subjected at several different times since their deposition. Other reasons are the irregularity of the beds and their great variation due to the shallow water conditions that prevailed throughout the greater portion of the periods of deposition. Under these conditions rectangular blocks of rock are difficult to obtain, the amount of waste rock is excessive, and the labor required to dress the stones is prohibitive. In certain quarries some of the strata might be used to advantage for building and the less desirable stones used for ballast or for flux.

Another objection to some of the limestones for buildings is their change of color on weathering. Most of the limestones are dolomitic but the magnesium content varies in the different layers. When fresh the rock is all bluish but on weathering the more dolomitic layers become much whiter than the others. The limestones that border the cement rocks have a tendency to become blotched on weathering on account of their heterogeneous composition.

Notwithstanding these difficulties, however, limestone has been used in the past for foundations and occasional buildings and will, no doubt, long continue to be quarried for local use.

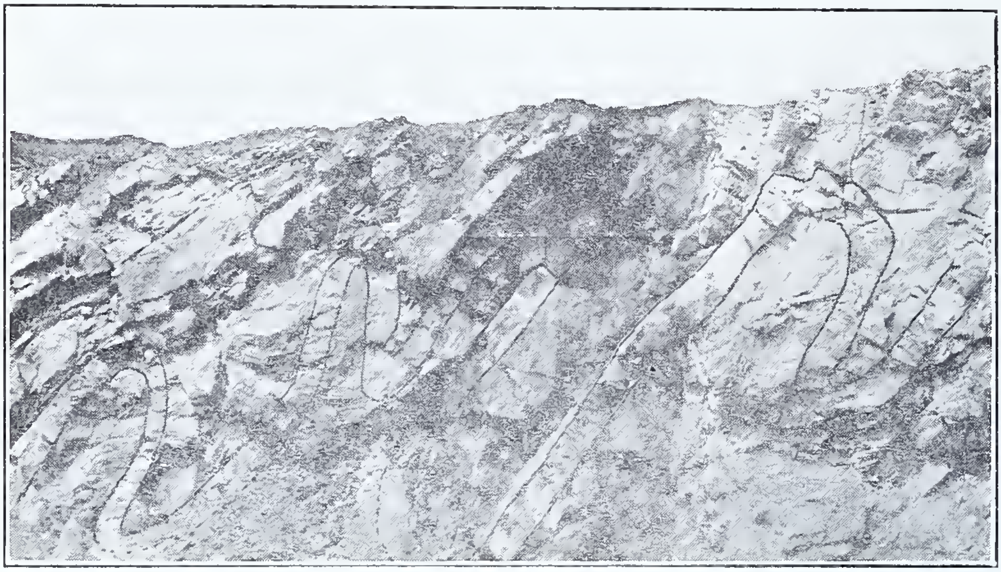
Lime.—Most of the quarries of this region have been worked for limestone to be burned for lime. As in all other parts of the State the small lime kilns operated for local supply have now been largely abandoned although here and there one finds some of these small kilns still in operation. In only a few places in these three counties has any large lime plant been developed for the shipment of lime to other sections. Unless extreme care is taken it is not possible to produce lime of uniform composition. For agricultural use and for plastering the lime produced in almost any part of the region is satisfactory but it would be difficult to produce lime for the chemical trade. One of the most important lime plants of the region is that of the Industrial Limestone Company on the Lehigh and New England R. R. about 4 miles north of Bethlehem, near Hanoverville. Some low magnesian layers of the Beekmantown limestone were found originally at this site and, on the assumption that a large body of such stone was present, a cement company was organized and the construction of a Portland cement plant started. High magnesian stone was encountered on further examination and the cement project was abandoned. The quarry does, however, furnish considerable low magnesian stone that is shipped to one of the cement companies but the bulk of the stone is burned for lime. Some highly siliceous gnarly layers are crushed for road metal and concrete. Prof. D. S. Chamberlain, Lehigh University, made a detailed study of some of the layers exposed in the quarry face a few years ago, particularly with reference to a prominent dolomitic bed. A photograph of the quarry and also a table of analyses abstracted from his report follow:

Analyses of limestone from Industrial Limestone Co. quarry, Hanoverville.

[D. S. Chamberlin, Analyst.]

No.	SiO_2	Fe_2O_3-Al_2O_3	$CaCO_3$	$MgCO_3$
1	5.74	3.72	85.75	2.81
2	4.50	1.48	61.80	32.50
3	6.28	10.82	41.06	40.90
4	3.68	1.84	64.80	30.03
5	2.42	12.46	85.50	1.25
6	5.18	17.78	38.10	38.05
7	6.50	1.14	89.25	2.34
8	5.40	1.12	55.60	38.60
9	3.82	17.54	57.65	21.02
10	7.46	0.50	88.94	2.85
11	5.64	1.18	78.00	15.80
12	4.20	0.46	89.85	6.44
13	4.06	9.14	79.55	6.33
14	5.80	5.58	54.53	34.65
15	4.34	10.50	80.00	4.89
16	6.56	0.82	56.85	36.65
17	5.70	0.24	92.45	2.02
18	6.48	4.04	88.45	2.77
19	4.88	0.82	55.44	38.94
20	could	not	be	sampled
21	6.52	0.88	55.15	38.21
22	5.54	5.08	84.97	3.73

PLATE VIII.



Folding in Industrial Limestone Co. quarry, Hanoverville.

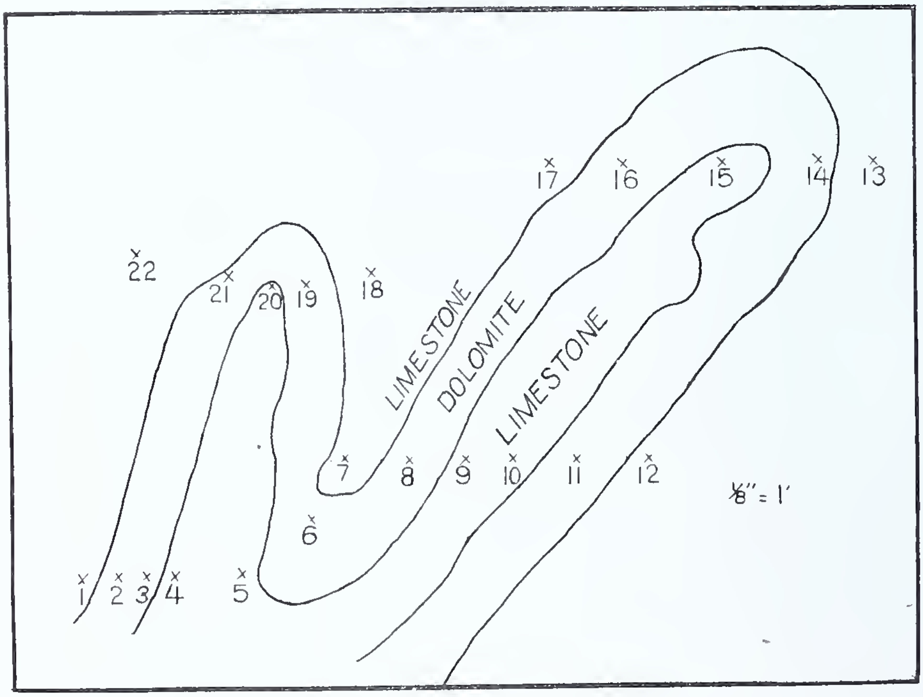


Figure 4. Diagram showing location of samples taken in quarry of Industrial Limestone Company, Hanoverville.

Crushed stone.—As in other parts of the State the Cambro-Ordovician limestones of this section have been extensively used for roads and for concrete aggregate. Except for occasional shaly bands, practically all the stone will meet the rigid specifications of the State Highway Department. Scores of quarries have been opened to supply local demands but most of them are of moderate size. In the vicinity of the larger towns some fairly large quarries have been developed to supply the demands for concrete material. One of the largest in the district is in the southwestern part of Allentown. The same quarry has furnished stone for lime but in smaller quantities.

Cement.—The most valuable economic mineral product of the region is the cement rock of the Jacksonburg formation. Nowhere else in the entire country is there known to be another occurrence of argillaceous low-magnesian limestone equally well adapted to the manufacture of Portland cement. The Lehigh district, as it is called, embracing the cement plants of Northampton, Lehigh and Berks counties and three plants in New Jersey, produces about 25 per cent of all the Portland cement of the United States, a pre-eminent position which it has held from the beginning of the industry in this country. With the exception of some high calcium limestones that are brought into the district from other regions in small quantities by a few of the companies whose local quarries furnish stone slightly deficient in the calcium content, all of the required stone comes from the Jacksonburg formation. There are 15 cement companies operating in the Pennsylvania portion of the district, several of which have two or more quarries and plants.

As in other regions the manufacture of natural hydraulic cement preceded that of Portland cement. In New York the construction of the Erie Canal in 1818-19 led to the discovery of natural hydraulic cement; in this State the digging of the canal of the Lehigh Coal & Navigation Company accomplished the same object. Rock suitable for hydraulic cement was found just above Lehigh Gap, where Palmerton is now located, and also at Siegfried's Bridge (now Siegfried). The rock at the former locality seemed to be preferable and a cement mill was built at Lehigh Gap under the direction of the company's engineers. This was operated by Samuel Glace from 1826-1830 and furnished material for many of the canal locks. When the best cement rock was exhausted near Lehigh Gap, for a time material was quarried about 6 miles east of the Gap and hauled to the plant. However, in 1830 it was decided to abandon the mill and erect a new one at Siegfried's Bridge where suitable rock was known to exist. In a small pamphlet by William H. Glace entitled "A Narrative of Hydraulic Cement Mined in the Lehigh Valley" the following description is given:

"Capt. Theodore H. Howell, residing at Siegfrieds, informed me that when he came there in 1837 there were four kilns erected and in operation. They were known as draw kilns, fire being placed in the eye at the bottom of the kilns, drawn at the bottom and hoisted up an incline plane or tramway and emptied into a hopper, where the stone were crushed by machinery shaped like a corn crusher, then dropped down and ground by burr millstones, then placed in boxes or trays with handles, then transported in scows to points on canal where needed. At that time the capacity of this plant was ten barrels per day."

Natural hydraulic cement continued to be manufactured in the region as shown by the following quotation from "History of the Lehigh Valley" by M. S. Henry, published in 1860.

"On the eastern side of the river, directly opposite the village (Whitehall, now Cementon), are the extensive Hydraulic Cement Works of E. Eckert and Co. These works have been in successful operation for a number of years, and the cement (which is mined in the neighborhood) is said to be equal in every respect to the celebrated Rosendale cement." (p. 302)

As early as 1867 David O. Saylor, who was at the head of a natural hydraulic cement company located at Coplay and called the Coplay Cement Company, began experimentation to try to improve the quality of their cement. In the preceding year the first Portland cement was brought to this country from England where it had been manufactured for several years, and this fact seemed to act as a stimulus to cement manufacturers in this country. By selecting the stone carefully Saylor finally succeeded about 1872 in making Portland cement which was exhibited at the Centennial Exposition where it received a "certificate of award."

The Coplay Cement Company (now the Coplay Cement Manufacturing Company) continued to make Portland cement, steadily improving its quality, while other plants were soon started in the same vicinity. For some years many difficulties were encountered while the importations of Portland cement from England were gradually increasing. In time, however, the Portland cement of the Lehigh district acquired the reputation, which it still holds, as the equal of any Portland cement made and cement importations practically ceased. The situation in 1878 is described by Prime[25] in his report in the Geology of Lehigh and Northampton Counties.

"Two companies, as mentioned in Report DD, have tried to utilize the hydraulic properties of this limestone in Northampton county, but neither of them have done much of anything in the last four or five years, and every time the quarries have been visited by members of the present geological survey they have been found standing unworked. These companies are "The Old Lehigh Cement Works" and "The Allen Cement Company".

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[25] Pa. Sec. Geol. Surv. Report D3, Vol. I, pp. 164, 165, 1883.

"It must not be supposed that because these companies have been apparently unsuccessful, that there is no future in the business of manufacturing hydraulic cement in this part of the State: on the contrary the success of the Copley Cement Company shows what perseverance under difficulties can and does accomplish. Of course the composition of some of the cement-stone beds is far more favorable to the manufacture of cement than that of others, but all may be more or less profitably utilized for careful intermixture. There is no reason why the manufacture of hydraulic and Portland cements should not be slowly and surely extended, not only rendering this portion of the State free from foreign competitors, but actually rivaling these in many of the western markets on account of the excellence of the product and the cheapness of freights."

For many years both natural and Portland cements were made in the district, in some cases even by the same company, but at present little natural cement is produced. Only a few years ago a natural cement company located at Egypt, ceased operating and dismantled its kilns.

The Lehigh district enjoyed almost a monopoly in the manufacture of Portland cement until it was discovered that an equally good product could be made from a variety of materials. Lehigh cement was shipped all over the country and much of it exported. While no other cement region occupies so favorable a position with reference to accessibility to good cement rock and fuel and proximity to great industrial centers, yet on account of freight charges the market for the cement of the Lehigh district is year by year restricted by the erection of cement plants in other sections of the country. Fortunately, however, the demand for Portland cement has kept pace with the growth of cement manufacturing plants so that the district continues to prosper regardless of increasing competition.

In this region many improvements have been made since the first successful manufacture of Portland cement. For a time the run of quarry was used with the result that some companies which owned quarries in which the rock had practically the composition now looked upon as most desirable, were able to produce a better product than other companies with less suitable rock. Also few companies were able to produce a uniform product on account of the variation in composition of the rock even in the same quarry. Now, however, the chemist of each company sees that the proper mixtures are used, and the physical tests also serve as a check, so that the old hit-or-miss method has given place to the exact scientific processes and the variations in the product are very slight.

The change in mechanical processes of manufacture have been equally great and each year mechanical modifications are introduced which tend to increase output and lower cost of production. The greatest improvements have been in the character of kilns by which the old upright kiln has given place to the modern rotary kiln now universally used throughout the region.

Cement rock and cement limestone.

The Jacksonburg strata as developed in this region consist of two fairly distinct types of rock, a basal member of crystalline high-grade limestone and an upper argillaceous limestone member that comprises most of the formation. In some places the two are sufficiently distinct to permit separate mapping but elsewhere they grade into each other and everywhere occasional layers of the basal type are interbedded within the more argillaceous upper member. The basal strata are commonly designated "cement limestone" and the upper "cement rock."

Effect on topography. In most places in the region the northern boundary of the cement rock can be accurately determined by an abrupt change in topography, the line of contact being at the base of the steep slopes which mark the southern margin of the slate belt. This change in slope is due to the relative ease with which the cement rock is removed by weathering, mainly solution, in comparison with the much less soluble slate.

In several places the southern boundary of the cement rock belt is also marked by a change in slope. The underlying limestone is more soluble than cement rock, and produces a more nearly level topography; hence the change from one belt to the other is marked by a change in slope.

"Cement limestone." The typical "cement limestone" of the region is a light to dark gray coarsely crystalline limestone which, when freshly broken, shows lustrous surfaces of dark calcite. Less commonly it is a dark-colored limestone closely resembling in appearance the underlying dolomitic limestones. It is usually massively bedded.

Normally the "cement limestone" runs high in $CaCO_3$ and low in $MgCO_3$ but it varies greatly in composition. The analyses given below are typical of the rock. In some quarries considerable rock is obtained in which the analyses show from 90 to 95 per cent $CaCO_3$. Also some quarries have a few beds that contain as much as 12 per cent $MgCO_3$, so much that the rock must be sorted out and discarded.

Analyses of "cement limestone."

	1	2	3	4
SiO_2	4.68	7.03	11.90	5.82
$Al_2O_3 + Fe_2O_3$	1.88	2.60	3.06	2.96
$CaCO_3$	89.95	87.00	77.50	86.20
$MgCO_3$	3.17	2.54	6.90	4.64

1. Limestone quarry of Dexter Portland Cement Co.
2. South side of quarry of Nazareth Cement Co.
3. Quarry one-fourth mile south of Christian Springs Hotel.
4. Limestone quarry of Bath Portland Cement Co.

The "cement limestone" contains numerous fossil remains, most of which, however, are fragmentary and scarcely determinable. They are seldom apparent except on the weathered surfaces of the rocks. They are of the same kinds as those contained in the limestone layers interbedded with the argillaceous cement rock. Fragments of small crinoid stems are most abundant but locally bryozoans are very common. The bryozoans belong to several different kinds, of which the branching and the bead-like colonies are most abundant. Poorly-preserved brachiopods are also found occasionally.

Geologic structure and relation.—The massive character of the "cement limestone" beds has prevented them from crumpling, but steeply dipping and overturned folds are present. In the quarry of the Coplay Cement Manufacturing Company on the west bank of Lehigh River there is an overturned synclinal fold shown in the south side of quarry. The syncline is overturned to the north so that the "cement limestone" both overlies and underlies a mass of "cement rock" with all the beds dipping to the southeast. In the quarry of the Nazareth Cement Company the "cement limestone" strikes N 55° W and dips 42° NE.

Elsewhere in the region the "cement limestone" dips gently to the north or northwest at low angles and disappears beneath the "cement rock." This "cement limestone" is of variable thickness, ranging from 100 to almost 200 feet. The greatest thickness is near Nazareth where it can be determined with a fair degree of accuracy to be approximately 200 feet thick. In the vicinity of Bath it scarcely exceeds 100 feet although the exact thickness cannot be determined.

The "cement limestone" grades into the overlying argillaceous limestone or "cement rock" by an intermediate band of interbedded, relatively pure limestone and impure argillaceous limestone strata. For that reason the two kinds of rock although lithologically dissimilar are regarded as constituting a single geologic formation.

At the base the "cement limestone" is in contact with the Beekmantown magnesian limestones. In this region the two formations are approximately conformable although to the eastward in New Jersey a marked erosional unconformity is shown in many places.

Glacial clay of variable thickness, with included cobbles and boulders, rests upon the "cement limestone." The glacial cover interferes with the determination of the position of the formation boundaries.

Where the "cement limestone" is well developed it is common for the cement companies to open quarries for material high in $CaCO_3$ to mix with the "cement rock." The Bath, Pennsylvania, Dexter, Phoenix and other companies have quarries in the "cement limestone." The Nazareth Cement Company has its quarry opened on the contact of the two kinds of rocks, the "cement limestone" occupying the southern part of the quarry and the "cement rock" the northern part.

"Cement rock." The "cement rock" is an argillaceous intermediate both in composition and stratigraphic position between pure limestone and shale or slate. In color it suggests the overlying Ordovician slates and in many places it shows marked slaty cleavage. A freshly broken piece is bluish-black in color and shows glistening particles of sericite too fine to be individually distinguishable except as light is reflected by them. The unaltered rock breaks partially along cleavage planes and partially along bedding planes, producing hackly or in some cases conchoidal surfaces that are unlike those of either the pure limestones beneath or the slates above. As the rock weathers, however, it separates into small cleavage fragments so similar to those resulting from the decomposition and disintegration of slate that it is difficult to distinguish between a slate soil and a "cement rock" soil. Both are filled with thin rock fragments of a light yellowish-gray color varying in size up to 1 inch in length.

In almost every quarry the rock shows the effect of great compression by which it has been shattered, permitting water carrying mineral matter in solution to precipitate quartz and calcite in the open fissures and irregular cavities. In places the vein matter is pure white calcite, in other places white granular quartz, but more commonly a mixture of the two. The white veins contrasting with the black rock are very prominent in the working faces of most quarries. The veins are roughly parallel and tend to follow bedding planes, although they break across the beds in many places. Smooth slickensided surfaces coated with a soft black carbonaceous substance resembling graphite are very common on the vein walls.

Small cubes of pyrite are frequently noticed near the veins and occasionally in rock where the vein material is absent. Purple and green fluorite have also been found in a few localities as vein material.

The chemical composition of the "cement rock" changes from bed to bed or even in the same bed within a single quarry opening. In some quarries the average rock contains almost exactly the right proportion of the various materials required for the best grade of Portland cement. Several plants in the district for months at a time do not find it necessary to add either pure limestone or clay. In most quarries the rock varies so that tracks must be run to several parts and the requisite mixture obtained by the proper combination of the various kinds of rock. In other quarries, however, the average rock runs too low in $CaCO_3$ so that it is always necessary to add some high grade limestone. Some of the plants are fortunate enough to have quarries in the underlying "cement limestone" while others must bring limestone from a distance. Much limestone from Annville, Lebanon County, Pa., is used in the Lehigh district. In a few quarries the average rock runs too high in $CaCO_3$ so that some other material must be added at times. For this purpose the local residual limestone and glacial clays are utilized.

With few exceptions the basal beds of "cement rock" are higher in lime than the upper strata. Accordingly a plant whose quarry is located near the northern margin of the belt and working the upper beds will need to add high grade limestone to the "cement rock," and a plant with a quarry near the southern margin of the belt and working the basal beds may need to add some clay at times. The Penn Allen and the Dexter companies show this very well, the former finding it necessary to add limestone from other points while the latter occasionally is required to add some clay.

In general the "cement rock" toward the western part of the district runs too low in $CaCO_3$ and the plants located there must buy limestone. The rock in the central and eastern part of the belt averages almost the desired composition for Portland cement, but requires at times a small admixture of clay.

The change in composition of the "cement rock" in depth is well shown in the following series of analyses of rock in a 350-foot boring made by the Atlas Cement Company in their quarry at Northampton. The last 40 feet penetrated was evidently the underlying cement limestone while occasional other high lime analyses are explained by the presence of layers of pure limestone interbedded with the argillaceous limestone ("cement rock").

Analyses of "cement rock" in 350-foot boring in quarry of Atlas Cement Company, Northampton.

Date received 1908	Depth Feet	SiO_2	Al_2O_3 Fe_2O_3	$CaCO_3$	$MgCO_3$	Total
	0- 5			64.61		
	5- 10			65.54		
	10- 15			63.85		
	15- 20			65.29		
	20- 25			63.00		
	25- 30			62.07		
	30- 35			62.09		
	35- 40			61.17		
	40- 45			61.23		
	45- 50			64.01		
6-23	Average of first 50 feet	21.72	7.88	63.27	5.33	98.20
	50- 55			63.57		
	55- 60			64.91		
	60- 65			56.55		
	65- 70			59.52		
	70- 75			67.92		
	75- 80			69.26		
	80- 85			69.19		
	85- 90			69.19		
	90- 95			67.09		
	95-100			66.25		
6-23	Average of 50 to 100 feet	21.42	8.26	64.42	4.45	98.55

Analyses of "cement rock" in 350-foot boring in quarry of Atlas Cement Company, Northampton—Continued.

Date received 1908	Depth Feet	SiO_2	Al_2O_3	$CaCO_3$ Fe_2O_3	$MgCO_3$	Total
	100-105			68.04		
	105-110			67.62		
	110-115			65.62		
	115-120			66.64		
	120-125			67.10		
	125-130			64.80		
	130-135			66.59		
	135-140			72.12		
	140-145			65.69		
	145-150			63.49		
6-24	Average of 100 to 150 feet	19.36	7.90	66.80	4.33	98.39
	150-155			66.16		
	155-160			64.97		
	160-165			66.51		
	165-170			64.63		
	170-175			65.91		
	175-180			69.45		
	180-185			69.10		
	185-190			68.93		
	190-195			65.15		
	195-200			69.28		
6-24	Average of 150 to 200 feet	17.22	8.02	67.44	4.95	97.63
	200-205			71.35		
	205-210			63.44		
	210-215			61.72		
	215-220			61.21		
	220-225			68.77		
	225-230			74.70		
	230-235			76.85		
	235-240			77.54		
	240-245			78.40		
	245-250			77.71		
6-24	Average of 200 to 250 feet	16.28	[illegible]	71.18	4.85	99.31
	250-255			74.32		
	255-260			71.39		
	260-265			78.10		
	265-270			79.99		
	270-275			76.80		
	275-280			71.65		
	280-285			74.58		
	285-290			75.02		
	290-295			73.11		
	295-300			72.69		
6-29	Average of 250 to 300 feet	13.24	7.32	74.78	4.18	99.52
	300-305			72.24		
	305-310			74.79		
	310-315			81.41		
	315-320			85.82		
	320-325			78.92		
	325-330			79.26		
	330-335			78.40		
	335-340			78.40		
	340-345			78.15		
	345-350			78.06		
7-20	Average of 300 to 350 feet	11.08	5.88	78.53	3.58	99.07

In addition to the substances given in the above analyses small quantities of TiO_2, FeO, MnO, P_2O_5, SrO, CaS, K_2O, and Na_2O have been found in the "cement rock" of the region. The effect of these in determining the quality of the cement is problematical. H. M. Ullman and J. W. Boyer, in a paper in Chemical Engineer, November, 1909, give a series of determinations of TiO_2 in specimens of "cement rock" from this region. They range from 0.14 to 0.24 per cent.

Meade[26] gives a complete analysis made by himself of a sample of "cement rock" from the quarry of the Dexter Portland Cement Company that has practically the correct composition for burning. It is as follows:

Complete analysis of "cement rock" from quarry of Dexter Portland Cement Company.

SiO_2	13.44	CaO	41.84	S	0.38
TiO_2	0.23	MgO	1.94	C	0.75
Al_2O_3	4.55	Na_2O	0.31	CO_2	32.94
Fe_2O_3	0.56	K_2O	0.72	H_2O	1.55
FeO	0.83	P_2O_5	0.22		
MnO	0.06				100.32

The writer has made careful search for fossils in the "cement rock" of the region but has found only one specimen in the typical black argillaceous limestone. This is a fairly well preserved specimen of a graptolite found in the old quarry of the Coplay Cement Manufacturing Company. It is probable that the carbonaceous matter of the rock which is responsible for the dark color is mainly due to the remains of graptolites that disintegrated during the metamorphism which the rock has undergone.

The occasional layers of crystalline limestone which are locally interbedded with the true "cement rock" contain abundant fossils most of which, however, are fragmentary. They can scarcely be recognized except on weathered surfaces. At the large quarry of the Atlas Cement Company and also the one near Howertown many crinoid stems, bryozoa, and brachiopods have been found.

In many quarries it is difficult to determine the bedding planes unless an interbedded pure limestone stratum can be found. Where these are absent the quartz and calcite veins, which, in general, are present along the bedding planes, are useful in determining the structure. Almost invariably the "cement rock" strata are greatly crumpled and yet have low angles of dip. The normal direction of dip is toward the northwest beneath the Martinsburg slates, which constitute the slate hills, but in many quarries some beds can be found dipping in other directions.

When the region was subjected to the great dynamic forces which formed the Appalachian folds the "cement rock" strata were so weak that they yielded by minor folding and faulting resulting in local thickening of the different layers but without producing high angles of dip. In very few places can one find the "cement rock" dipping more than 45° and usually the dip is much less, while in the adjoining limestone belt vertical or even overturned beds are not uncommon.

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[26] Portland Cement, sec. ed. p. 50, Easton, Pa., 1911.

The crumpled character of the "cement rock," the absence of any beds sufficiently distinct to be recognized in different openings, and the lack of any continuous or approximately continuous section across the belt normal to the strike render the exact determination of the thickness impossible. The local thickening of the beds due to compression also needs to be taken into account in any estimates of thickness.

In the 350-foot bore hole of the Atlas Cement Company described above, 310 feet seems to be "cement rock" and the last 40 feet to be the underlying "cement limestone." The rocks here, although somewhat crumpled, were so nearly flat that we can safely assume 300 feet of cement rock strata. As the bore hole was started in the bottom of the quarry with somewhat more than 100 feet of "cement rock" above it the total thickness of "cement rock" in that place is about 400 feet. This is believed to be the maximum thickness within the region. From Weaversville to Nazareth the thickness scarcely exceeds 200 feet and may be less in the vicinity of Bath.

This decided difference in thickness of the "cement rock" may be partially due to local thickening as the rock yielded under compression at the close of the Ordovician and Carboniferous periods but is mainly explained by a greater deposition of muddy calcareous beds in the region of the Lehigh River than took place elsewhere.

The "cement rock" rests conformably upon the underlying "cement limestone." In some places the basal beds seem to dovetail into the upper beds of the underlying purer limestone. This is seen in the quarries of the Pennsylvania Cement Company east of Bath.

The "cement rock" is conformably overlain by the shales and slates of the Martinsburg formation.

In many places in the district glacial clays containing many cobbles and boulders overlie the "cement rock." This overlying debris, which must be removed before the rock is blasted down, is as much as 15 feet thick in depressions in the former land surface, although the average thickness of this cover is probably less than 5 feet.

Other limestones used for cement.

Reference has already been made to the presence of low magnesian limestones suitable for Portland cement manufacture that occur in the Beekmantown formation.

Along the Central Railroad of New Jersey a quarter of a mile north of Catasauqua the Lawrence Portland Cement Company operated a limestone quarry for many years. The rocks low in $MgCO_3$ were shipped to the cement plant at Siegfried and those containing too much $MgCO_3$ for cement were sold to the Crane Iron Company for flux. At times the company was able to use 75 per cent of the output for cement but at other times scarcely 25 per cent. In most cases the $MgCO_3$ content for each bed of rock was fairly uniform but in parts of the quarry a certain stratum was suitable for cement but changed in composition sufficiently to render it undesirable in other parts. Under the guidance of the chemist the quarrymen learned to detect the difference in appearance of the rocks low and high in $MgCO_3$ so that their separation was easy. Naturally, steam shovels could not be used as the different kinds of rock were thrown down together in blasting. The following analyses taken at approximately equal distances starting from the northwest corner and going in turn along the north, east, and south faces have been furnished by the Lawrence Portland Cement Company.

Analyses of limestones in quarry ¼ mile north of Catasauqua.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	9.02	7.82	12.91	12.38	12.81	7.43	13.90	5.56	1.94	5.18	5.70
Al_2O_3 Fe_2O_3	3.95	2.14	4.15	5.09	5.41	2.63	4.76	1.87	1.22	3.05	2.85
$CaCO_3$	82.12	85.70	79.65	79.03	75.50	85.32	76.94	87.23	92.57	83.30	85.63
$MgCO_3$	4.31	3.44	2.98	3.35	6.07	4.07	4.73	4.53	5.10	3.13	6.04

On a previous page there is a brief description of the quarry of the Industrial Limestone Company a few miles north of Bethlehem. Considerable low magnesian limestone from the quarry has been shipped to the Penn-Allen Portland Cement Co. The following analyses of this stone are furnished by the company:

Analyses of limestone from quarry of The Industrial Limestone Company.

	A	B	C
SiO_2	2.56	1.5	0.74
$Al_2O_3+Fe_2O_3$	0.74	0.22	[illegible]
$CaCO_3$	94.37	92.70	96.5[illegible]
$MgCO_3$	2.24	4.15	1.73

Analysis A was made by the Penn Allen Portland Cement Company and B and C by F. F. Hintze of Lehigh University.

A few years ago a quarry was opened in the small area of pre-Cambrian crystalline limestone along the right bank of Monocacy Creek just west of Pine Top. The quarry was operated by the Monocacy Stone Company. Some of the rock was sold to the cement companies of the region. (See p. 65)

The rock is similar in character and of approximately the same age as the famous Franklin limestone of New Jersey so extensively quarried in the vicinity of Franklin Furnace and McAfee. The following analyses show the general character of the rock:

Analyses of crystalline limestone quarried by the Monocacy Stone Company.

	A	B
$CaCO_3$	94.74	93.46
$MgCO_3$	1.96	1.75
Al_2O_3	.21	.69
SiO_2	2.08	2.78
Fe_2O_3	.37	.55
CaO	53.11	52.39
MgO	.94	.84
Fe	.26	.39

Sample A was of medium grain and dark in color.
Sample B was a coarsely crystalline white rock.

Clay.

As mentioned above, some of the cement plants near Nazareth are compelled to use a small quantity of clay with the cement rock to make the proper mixture for Portland cement. In most cases this is the local clay overlying the cement rock and represents the residium of insoluble materials left when the soluble portions of the rock were removed in solution. Some of it has been transported and deposited by the waters resulting from the melting of the ice sheet which once invaded the region. The glacial clays contain occasional cobbles and boulders.

At one time the Nazareth Cement Company operated a small clay pit near the mill but in most places the thin deposit of clay overlying the cement rock is more than sufficient for the needs of the plants. The above-mentioned company furnishes the following partial analyses of the local clays used.

Analyses of local clays used in manufacture of cement.

SiO_2	63.10	70.10
$Al_2O_3+Fe_2O_3$	20.62	20.04
CaO	.78	.30
MgO	2.70	1.25

Limestone and clay from other regions.

Several companies operating in the region who are compelled to buy limestone to mix with their cement rock, bring it from some distance beyond the borders of the district. The Annville limestones of Lebanon County, Pa., are used in several plants while some Franklin limestone from New Jersey is also shipped in. The Atlas Cement Company uses the latter in the manufacture of white cement. To mix with it they also ship in white clay, most of which comes from Saylorsburg, Monroe County, Pa. Most of the gypsum which is added to the clinker before grinding comes from western New York.

Analyses of Trenton (Annville) and Franklin limestones.

	A	B	C	D
$CaCO_3$	97.11	96.67	96.00	94.29
$MgCO_3$	1.12	1.34	2.54	3.14
SiO_2	0.36		0.46	
Al_2O_3	0.45	1.77	0.36	2.13
Fe_2O_3	0.45		0.36	

A. Annville limestone analyzed by R. K. Meade.
B. Average of 9 samples of Annville limestone analyzed by Atlas Cement Co.
C. Franklin limestone analyzed by R. K. Meade.
D. Average of 19 samples of Franklin limestone analyzed by Atlas Cement Co.

Quarry Methods.

The quarry methods used by the cement companies are similar throughout the district. If possible the quarry is opened in the side of a hill and the tracks are run in on the level. As the quarry is extended the quarry face becomes higher. In some places, however, it is necessary to open a quarry by excavating in a fairly level surface and then the rock must be hauled up an incline to the plant.

In almost every quarry the composition of the rock varies so much in different parts that it is advisable to have an extensive face with tracks radiating to different points in order to obtain a mixture of uniform composition by combining the rock of high and low lime content.

Formerly the rock was quarried in benches by using small drills and small blasts. Now, however, the companies have found it more economical to blow down enormous masses of rock at one time, in some places more than 30,000 tons. To do this churn drill holes are put down about 10 to 15 feet back from the quarry face and about the same distance apart and driven to the level of the bottom of the quarry which is usually nearly 100 feet. These holes are then charged with dynamite and all are fired simultaneously by electric exploders. The rock is so easily shattered that these great blasts break most of it sufficiently to be loaded into cars. The larger blocks are broken by small charges of dynamite placed in holes made by compressed air hand drills.

Most of the companies use steam shovels for loading the rock into cars although some loading is done by hand. In the quarries that are driven into a hillside on the level small locomotives or mules are used to haul the cars to the mill. Where the quarry is sunk below the level of the mill the cars are pushed by hand or hauled by mules to the foot of the incline where they are attached to a cable to be hauled up the slope. The rock is dumped into a bin or directly into the gyratory crushers.

Cement Manufacture.

In general there is little variation in the methods employed throughout the region for the manufacture of Portland cement although somewhat different types of machinery are used. The different stages are (1) coarse grinding, (2) drying, (3) fine grinding, (4) calcining, (5) cooling or seasoning, (6) mixing with gypsum and grinding the clinker, (7) seasoning in storage house preparatory to bagging or packing in barrels. As these various processes have been described in so many publications dealing with the technical side of cement manufacture they will be described only briefly here.

(1) The first stage of coarse grinding is done almost exclusively by great gyratory crushers. The rock properly combined is fed to the crushers from bins, dumped directly from the cars, or brought from rock house by belt conveyor. In some mills the crushed rock passes to a set of smaller gyratory crushers or rolls.

(2) The rock fragments are dried in short rotary kilns which in a few plants are connected with the ends of the burning kilns and thus use the heated gases that would otherwise escape at once into the air.

(3) Various kinds of machines are used for the fine grinding—ball mills, tube mills, Huntington mills, Griffin mills, cominuters, Fuller-Lehigh pulverizers, etc. One mill uses the Emerick air separator. Most of the mills grind the rock so that 95 per cent will pass through a 100-mesh screen and approximately 85 per cent will pass through a 200-mesh screen.

(4) From the mills the pulverized rock is taken to bins and from them is fed into the kilns. At present all the companies use rotary kilns. The older and smaller kilns are gradually being replaced by larger sizes. At first nearly all were about 40 feet long, then 60, 80, and 100 feet; recently one has been installed that is 220 feet long and 10 feet in diameter. It has been found that the fuel costs are considerably less in the larger kilns and the capacity is greatly increased.

The kilns are fired with coal ground so fine that about 95 per cent will pass through a 100-mesh screen. The coal dust is forced into the kiln by fans or compressed air.

The first kilns used in the district were upright. Several of these, called Schoefer kilns, are still to be seen at the plant of the Coplay Cement Manufacturing Company. They consist of three compartments, an upper heating chamber, a middle clinkering chamber, and a lower cooling chamber. The pulverized rock was mixed with water and moulded into bricks which were first dried and then carefully placed in the upper chamber by hand. The material passed in turn through the other chamber and was drawn out at the base. These kilns were not satisfactory as the material was not uniformly burned, the amount of labor required was excessive, and the production limited, as scarcely more than 100 barrels of cement could be burned in each kiln daily. On the other hand the fuel consumption was much less than that required in the rotary kilns, ranging from 45 to 65 pounds of coal per barrel of cement.

(5) In some mills the clinker is stored under cover for a short time before being ground but the practice of storing it in the open where it is allowed to season for several weeks before grinding is being adopted by many mills since the Dexter Portland Cement Company proved it to be a success.

(6) After cooling and seasoning the clinker is taken to mills for regrinding. In almost every mill the same type of machinery is used for grinding the clinker that is employed in pulverizing the rock. Before grinding, a definite proportion of gypsum is added to the clinker to retard the setting of the cement.

(7) From the mills the cement is taken to the storage bins where it remains for some time to season and is then withdrawn for shipment. It is shipped in barrels holding 380 pounds and in paper or cloth bags holding 95 pounds. The Bates valve bag is widely used in the district.

Economic Considerations.

The cement industry of the Lehigh district has undergone remarkable changes since it started. The price fell steadily before the war from $3.00 to $0.65 per barrel but since then has been considerably higher. The output with few exceptions, has been increased from year to year, and yet the market for the cement from this district has been gradually restricted on account of the building of plants in sections of the country formerly supplied by the Lehigh product. In no other part of the country can cement be produced at so low a price as in this district and the condition of the industry continues promising regardless of the competition and reduced prices. Increased efficiency has resulted and the Lehigh district plants are models for other cement companies throughout the country. Experimentation still continues and new types of machinery and new details in manufacturing are sure to result.

In some cases the companies have failed to appreciate the importance of a careful study of the structure of the cement rock strata by which their quarries could have been operated more economically. Likewise several of the plants might have been located more advantageously had the geology of the region been carefully studied in advance.

The possession of cement rock of so nearly the correct composition for Portland cement, a very unusual occurrence, and the close proximity to the great industrial centers of the country are the two great assets that have enabled the Lehigh cement district to achieve and maintain its pre-eminent position. With the skill and efficiency acquired by years of experience and the increasing demand for cement the cement companies may look forward to many years of prosperity.

Additional analyses of Cambro-Ordovician limestones of Northampton, Lehigh and Berks counties.

	1	2	3	4	5	6
$CaCO_3$	52.16	53.43	53.77		52.37	47.66
CaO				31.95		
$MgCO_3$	43.28	41.43	42.92		41.74	42.26
MgO				18.65		
SiO_2	1.90	4.77	1.68	2.70	4.95	6.94
Al_2O_3	0.58	2.20	1.10	2.62	.73	1.95
Fe_2O_3						1.05
S	0.020					
P	0.006					

	7	8a 19′-25′	8b 25′-30′	8c 30′-40′	8d 40′-50′	8e 50′-58′	8f 66′-70′	8g 70′-80′	8h 80′-85
$CaCO_3$	50.49	54.7	53.5	47.5	55.0	52.8	55.0	53.2	49.3
$MgCO_3$	41.04	43.7	43.0	34.0	41.5	11.2	43.5	41.5	35.2
SiO_2	5.67	0.89	2.02	11.92	1.79	3.63	0.82	2.81	3.69
Al_2O_3	1.59								
Fe_2O_3									
S	0.21								
P	0.006								

	8i 85′-90′	8j 90′-100′	8k 100′-110′	8l 110′-120′	8m 120′-130′	8n 130′-140′	8o 140′-149′	9
$CaCO_3$								82.44
$MgCO_3$								10.26
SiO_2	5.04	9.76	5.65	3.77	1.59	3.54	4.53	4.74
P								.003
S								.026
Fe_2O_3								
Al_2O_3								2.30

1. Tomstown limestone quarry at Island Park, south side of Lehigh River, Northampton County. Average of 108 cars shipped to Thomas Iron Co. Analysis by Thomas Iron Co.
2. Tomstown limestone. Redington quarry of Bethlehem Steel Co., Northampton County. Average analysis of stone quarried during 1916. Analyzed by Bethlehem Steel Co.
3. Conococheague limestone. Easton Lime Company's quarry along Bushkill Creek, Easton, Northampton County. Analysis by P. Shimer.
4. Tomstown limestone. O. E. Leh quarry at Redington, Northampton County. Analysis by Bethlehem Steel Co.
5. Conococheague limestone. J. M. Laubach quarry, Freemansburg, Northampton County. Average analysis of 110 cars made by Bethlehem Steel Co.
6. Conococheague limestone Wagner's quarry, west side of Saucon Creek, ½ mile southwest of Hellertown, Northampton County. Analysis made by Bethlehem Steel Co. is average of six month's run.
7. Conococheague limestone. Henry Schweitzer's quarry midway between Freemansburg and Altona, Northampton Co. Analysis by Bethlehem Steel Co.
8. a to o. Conococheague limestone Drill test hole at Chapman quarry of Bethlehem Steel Company along C. N. J. R. R. between Bethlehem and Freemansburg. Analysis by Bethlehem Steel Co.
9. Beekmantown limestone. Fogel's farm near Hecktown on L. & N. E. R. R., Northampton County. Analysis made by Bethlehem Steel Co., is average of 10 samples collected by C. A. Buck.

Additional analyses of Cambro-Ordovician limestones—Continued.

	10a	10b	11	12	13	14	15
$CaCO_3$	81.41	87.66	88.12		52.08	51.60	51.73
CaO				27.8			
$MgCO_3$	11.49	4.97	4.71		41.29	42.60	45.35
MgO				18.01			
SiO_2	4.50	5.30	4.70	8.97	3.80	3.30	1.20
Al_2O_3	1.89		1.33		1.12	1.75	0.65
Fe_2O_3	0.39	1.05	0.26		0.79	0.52	0.66
P		0.010					

	16a	16b	16c	16d	17a	17b	17c	18a	18b
$CaCO_3$					53.20	51.36	53.25	51.920	47.8[illegible]0
CaO	18.23	28.33	27.44	28.10					
$MgCO_3$					41.30	39.72	37.10	41.071	39.586
MgO	19.20	19.79	18.33	19.56					
SiO_2	6.40	5.89	8.91	6.77	2.32	4.70	4.42	5.650	11.260
Al_2O_3	1.39	1.40	2.31	2.75	1.50	2.68	3.17		
Fe_2O_3						0.92	1.11		
S						0.026	0.026	trace	trace
P					0.010	0.012	.010	.011	.021

	19	20	21	22	23a	23b	24
$CaCO_3$	49.316	83.632	70.750	56.220	51.558	86.036	51.603
$MgCO_3$	40.463	5.466	15.256	31.201	35.216	4.594	32.917
SiO_2	8.980	7.850	11.070	10.980	10.750	8.400	13.490
Al_2O_3	0.70		.860	.300	.140	.065	
S							.147
P	.006	.026	.019	.005	.018	.016	.012

10. Beekmantown limestone. Reyer's quarry, 1 mile east of Northampton, Northampton County. a. Analysis by the Bethlehem Steel Co. b. Analysis by Thomas Iron Co.

11. Beekmantown limestone. Calcite Company quarry, ¾ mile southeast of Northampton, Northampton County. Analysis by Bethlehem Steel Co.

12. Tomstown limestone. Morey farm, ½ mile southwest of Center Valley, Lehigh County. Analyzed by Bethlehem Steel Co.

13. Tomstown limestone. Ackers quarry, south of East Allentown and a short distance northeast of bend in the Lehigh River, Lehigh County. Analyzed by Bethlehem Steel Co.

14. Tomstown limestone. New Jersey Zinc Co. quarry, along Lehigh River just north of East Allentown, Lehigh Co. Analysis by Bethlehem Steel Co. Material used for flux at Palmerton plant of N. J. Zinc Co.

15. Allentown limestone. Hardners quarry along Little Lehigh Creek, Allentown, Lehigh County. Analysis by Bethlehem Steel Co.

16. Beekmantown limestone. Outcrops at Ueberroth pit of New Jersey Zinc Company's zinc mine ½ mile north of Friedensville, Lehigh County. Analyses by Bethlehem Steel Co.

17. Beekmantown limestone. Eberhart's quarry, west side of Lehigh River, opposite Catasauqua, just north of junction of Coplay Creek and Lehigh River, Lehigh County. a. Analysis by the Bethlehem Steel Co. b. and c. Analyses by the Thomas Iron Co. b. Represents the average of 183 cars shipped to the Thomas Iron Co. during the first half of 1920 and c. the average of 166 cars shipped during the latter half of 1920.

18. Beekmantown limestone. Thomas Iron Company's quarry, ¾ mile north-northwest of Alburtis, Lehigh County. a. Limestone, hard, compact, and of a bluish gray color. b. Limestone, compact, highly crystalline, and of a bluish gray color. (Pa. Second Geol. Survey Report M. p. 76).

19. Beekmantown limestone. Mary Kohler quarry, ¾ mile west of Whitehall station, L. V. R. R. Brecciated limestone; various shades of blue and gray. (MM. p. 309.)

20. Beekmantown limestone. Ironton Railroad Company's quarry. 1 mile southeast of Ironton, Lehigh County. Hard and compact; bluish gray. (MM p. 310.)

21. Beekmantown limestone. Edward Guth quarry. At Guth's Station, 4½ miles west of Catasauqua., Lehigh County. Fine grained; dark blue, with slaty structure. (MM. p. 310.)

22. Beekmantown limestone. Thomas Iron Company's quarry, at Guth's station, Lehigh County. Fine grained, bluish gray; with some quartz. (MM. p. 310.)

23. Beekmantown limestone. Eph. Wenner quarries at Jordan Bridge of the Catasauqua & Fogelsville R. R. 4½ miles northwest of Allentown, Lehigh County. Leased by Crane Iron Co. a. "Hard limestone." fine-grained: hard and brittle; spotted with pyrites; bluish gray. b. "Soft limestone." Comparatively soft, fine grained, dark blue, with laminated structure. (MM. p. 309.)

24. Beekmantown limestone. Mrs. Kuhn's quarry 1½ miles northeast of Trexlertown, Lehigh County. Limestone, compact, siliceous and of a light bluish gray color. (M. p. 76.)

Additional analyses of Cambro-Ordovician limestones—Continued.

	25	26	27	28	29	30	31	32
$CaCO_3$	48.630	74.05	69.00	52.857	53.839	54.714	26.053	51.839
$MgCO_3$	40.410	4.09	5.70	42.779	42.042	43.380	19.077	40.523
SiO_2	9.240	12.66	19.82	3.890	3.410	1.220	50.610	7.170
Al_2O_3	----------	5.19	5.40	.650	.810	.990	2.330	.860
Fe_2O_3	----------	1.87						
S	.005	----------	----------	----------	----------	----------	----------	----------
P	.012	----------	----------	.004	.008	.003	----------	.005

	33	34	35	36	37	38	39	40
$CaCO_3$	19.821	87.267	55.053	54.643	63.928	53.392	52.357	54.267
$MgCO_3$	14.529	8.324	38.094	41.598	12.884	41.848	40.363	42.611
SiO_2	64.370	3.480	6.280	3.400	20.110	3.600	6.420	2,470
Al_2O_3, Fe_2O_3	.810	.810	.730	.750	1.730	1.090	.550	[illegible]
P	----------	.006	----------	----------	----------	----------	.006	----------

	41	42	43	44	45	46	47	48
$CaCO_3$	91.964	95.125	59.875	66.535	79.107	87.642	92.214	63.107
$MgCO_3$	2.337	1.036	36.024	**21.645**	**14.227**	**9.837**	**4.986**	**27.402**
SiO_2	5.910	3.680	2.760	9.630	5.690	2.2 0	2.750	8.210
Al_2O_3, Fe_2O_3	.180	.210	1.660	1.940	.520	.570	.420	1.450
P	----------	----------	.009	----------	.003	----------	----------	----------

25. Beekmantown limestone. Frantz quarry, 1½ miles northeast of Trexlertown, Lehigb County. Limestone, hard, siliceous, of a dark blue color. (M. p. 76.)

26. Jacksonburg cement rock. Whitehall Cement Company's quarry, Cementon, Lehigb County. Analysis by Whitehall Cement Co.

27. Jacksonburg cement rock. Typical analysis of stone in quarry No. 2. of Coplay Cement Manufacturing Co., Lehigb County. Analysis by company.

28. Quarry of Jonas Shaub, 2 miles east of Seisboltzville near Lehigh County line, Berks County. Analysis by A. S. McCreath. (D3, vol. 2 p. 144.)

29. Schall quarry ½ mile north of Dale, Berks County. Analysis by A. S. McCreath, (D3, vol. 2, pp. 146-147.)

30. Clemmer quarry, ¼ mile north of Clayton, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 149.)

31. Diehl quarry, ½ mile below Clayton, Berks County. Analysis by A. S. McCreath, (D3, vol. 2, p. 149.)

32. Oberholtzer quarry, ½ mile northeast of Bechtelsville, Berks County. Analysis by A. S. McCreath, (D3, vol. 2, p. 151.)

33. Miller quarry ½ mile southwest of Bechtelsville, Berks County. Analysis by A. S. McCreath, (D3, vol. 2, p. 151.)

34. Levi Gresh quarry ¼ mile northeast of Gresbville, Berks County. Analysis by A. S. McCreath, (D3, vol. 2, p. 154.)

35. Dandheiser quarry, ¼ mile west of Greshville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 155.)

36. Keely quarry, ¼ mile west of Greshville, Berks County. Analysis by A. S. McCreath, (D3, vol. 2, p. 155.)

37. Rapp quarry, 1¼ miles southeast of Earlville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 156.)

38. Quarry ¼ mile north of Earlville, Berks County. Analysis by A. S. McCreatb. (D3, vol 2, p. 160.)

39. Quarry on Powder Mill Creek (Trout Run) ⅔ mile north of Earlville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 161.)

40. West bluff of Manatawney Creek ½ mile north of Rahbit Hill, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 162.)

41. David Yoder quarry, ⅓ mile northeast of Manatawney (Pleasantville), Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 165.)

42. Williams quarry, ¼ mile northwest of Manatawney (Pleasantville), Berks County. Analysis by A. S. McCreath, (D3, vol. 2, p. 165.)

43. Schollenberger quarry, east of Pine Creek, ½ mile north of Manatawney (Pleasantville), Berks County. Analysis by A. S. McCreath. (D3, vol. 2, pp. 165-166.)

44. Weidners quarry, 1 mile south of Lobachsville, Berks County. Analysis by A. S. McCreath. (D3, Vol. 2, p. 166.)

45. John Keim quarry, 1 mile west of Lobachsville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 167.)

46. Deisher quarry, 1½ miles northeast of Friedensburg, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, 168.)

47. Bertolet quarry, 1 mile east of Friedensburg, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, 169.)

48. Kauffman quarry, 1½ miles southeast of Friedensburg, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 170.)

Additional analyses of Cambro-Ordovician limestones—Concluded.

	49	50	51	52	53	54	55
$CaCO_3$	96.178	88.857	90.357	71.178	95.667	95.500	97.321
$MgCO_3$	2.176	3.783	2.800	23.263	2.081	2.724	1.496
SiO_2	1.770	6.800	6.640	4.770	1.010	1.940	1.320
Al_2O_3 Fe_2O_3	.290	.310	.310	1.080	.350	.230	.210
P				.035			

	56	57	58	59	60	61	62
$CaCO_3$	51.303	92.142	95.575	90.214	81.286	89.214	60.089
$MgCO_3$	32.713	1.832	1.535	6.420	10.412	2.714	38.185
SiO_2	15.220	5.820	2.650	3.700	7.870	7.890	1.610
Al_2O_3 Fe_2O_3	1.060	.500	.280	.210	.870	.520	.230

	63	64	65	66	67	68a	68b
$CaCO_3$	80.160	87.910	86.889	67.821	51.303	52.67	47.316
$MgCO_3$	9.459	7.340	5.728	24.025	37.557	44.64	40.500
SiO_2	9.100	4.390	7.240	7.050	9.130	1.42	9.900
Al_2O_3 Fe_2O_3	.980	.370	.470	1.340	1.960	1.27	2.275
P				.009			

49. Ellis Winter quarry, 1 mile northwest of Griesemersville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 171.)

50. S. Houck quarry, 1½ miles northwest of Griesemersville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 171.)

51. Guldin quarry, ¾ mile north of Yellow House. Analysis by A. S. McCreath. (D3, vol. 2, p. 172.)

52. Weaver quarry, 2 miles northwest of Griesemersville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 173.)

53. Seth Grim quarry, 1¾ miles northwest of Griesemersville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 173.)

54. Kemmerer quarry, 1½ miles west of Griesemersville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 174.)

55. Sneider quarry, 1 mile northeast of Oley Line, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 175.)

56. Paudenbusch quarries, ¾ mile east of Oley Line, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 176.)

57. Ezra Griesemer quarry, 1 mile southwest of Griesemersville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 176.)

58. Fischer quarries, 1 mile southwest of Griesemersville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 177.)

59. Herbein quarry, 1¼ miles southwest of Griesemersville, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 177.)

60. Marquart quarry near Limekiln Creek, 1 mile southeast of Oley Line, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 178.)

61. Quarry ½ mile southeast of Oley Line, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 179.)

62. A. Knabb quarry, ½ mile northwest of Oley Line, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 180.)

63. S. Kaufmans quarry, ½ mile south of Oley Line, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 185.)

64. Ritter quarry, ¾ mile east of Jacksonwald, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 186.)

65. Tyson quarry, ½ mile east of Jacksonwald, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 187.)

66. Big Dam quarry, along Schuylkill River, 1½ miles southeast of Reading, Berks County. Analysis by A. S. McCreath. (D3, vol. 2, p. 189.)

67. Exposure on P. & R. cut, 1 mile south of Reading, Pa. Analysis by A. S. McCreath. (D3, vol. 2, p. 189.)

68. Long's quarry, right bank of Schuylkill River, opposite south part of Reading, Berks County. Analysis by Booth, Garrett and Blair. (D3, vol. 2, p. 195.)

LEBANON AND DAUPHIN COUNTIES.

The Great Valley limestones of Cambro-Ordovician age cut across the southern half of Lebanon and Dauphin counties in an east-west trending band that is about 12 miles wide near the Berks County line but gradually narrows westward. In the vicinity of the Susquehanna River it is broken into smaller areas by an intervening band of slate.

The limestones of this section as yet have not been carefully studied, so a classification is not offered here. It is clearly recognized, however, that there are several different formations possessing distinct lithologic characteristics and containing organic remains. Fossils are scarce so that most of the exposures show none although minute search of the weathered strata will doubtless bring to light more than are ordinarily believed to exist.

In the past when the principal use for the limestones was for the manufacture of agricultural lime, with minor uses as flux for the local iron furnaces and for building stone, scores of limestone quarries were opened throughout the region. The quality of the stone was always to be considered but was of less consequence than its proximity to the consumer. At present the only quarries in continuous operation are those that furnish superior stone for flux and cement and are located near the railroad. Merely by accident the Philadelphia and Reading R. R. passes through the area containing the best stone of the region, stone of such unusually fine quality that railroad facilities would doubtless have been provided if the main line of the railroad had been located elsewhere.

Most of the limestones of the region are high in magnesium carbonate as well as silica and hence of little value for flux, cement, or high grade lime. They are well adapted for concrete and road metal and have been quarried for such use near Harrisburg, Lebanon and the other towns of the district. They would be valuable for building purposes if the cracks, joints and uneven bedding planes were less numerous. As an illustration of the demand for high quality stone only, it may be mentioned that at Cornwall the Bethlehem Steel Company is working an extensive deposit of magnetite iron ore by the open cut method which requires the removal of large quantities of overlying Cambro-Ordovician limestones of average quality. Occasionally some of the stone is sold for local use on the roads or for concrete but in the main the stone is wasted.

High-grade Limestone.

The only sections of this region worthy of special discussion are the area of high grade limestone that extends as a narrow band from Myerstown to Palmyra and the quarries at Steelton that are extensively worked for flux by the Bethlehem Steel Company. In

Part IV, Annual Report of the Second Geological Survey of Pennsylvania for 1886 (pp. 1523-1554) there are brief descriptions of 32 limestone quarries in Dauphin and 43 in Lebanon counties.

Annville limestone.—The best limestone of the district and of its kind equal to any in the State is contained in a belt only a few hundred feet wide and about 15 miles long that passes through or very near Myerstown, Lebanon, Annville, and Palmyra. In this area limestone about 400 feet thick averages more than 95 per cent calcium carbonate. This stone has been quarried most extensively in the vicinity of Annville and consequently the name "Annville limestone" has become a trade name for the product of the entire belt.

The high calcium stone lies between dolomitic strata that are generally higher in silica. For certain uses some of these other stones may be included in a shipment and this must be borne in mind in the examination of the analyses that follow. Adjoining the quarries of the best stone there are in places other quarries that furnish stone of somewhat inferior grade for purposes whose specifications are less rigid H. E. Millard, the largest operator of the district, with one quarry at Myerstown, 7 at Annville, and one at Palmyra claims that all his quarries contain limestone with 98 per cent or more of calcium carbonate although the analyses of the shipments from the quarries of the belt seldom show material of this quality. With sufficient care in quarrying most of the producers could ship stone averaging more than 96 or even 98 per cent calcium carbonate.

The stone from the region is sold principally to the Portland cement companies of the Lehigh district that require some high grade calcite stone to mix with the cement rock of their quarries that is slightly deficient in its $CaCO_3$ content, and to the iron and steel companies of the State. Considerable is burned for lime and a small quantity is used as crushed stone.

The chief obstacles in quarrying this desirable limestone are the presence of water at comparatively shallow depths and the overburden of residual clay. In some places the strata are so shattered and cavernous that any quarry opening receives the drainage from several acres and few are so located that they are self-draining. Accordingly the necessary pumping considerably increases the cost of operation. The overburden is of variable thickness and in some localities is too thick to warrant removal at the present time.

At the quarries of Lawrence Portland Cement Co., and the Whitehall Portland Cement Co. a short distance northwest of Annville, bands of decomposed limestone about 75 feet wide are exposed. It has returned to the original unconsolidated condition of a chalky marl by the recent solution of the cementing calcium carbonate. For the ordinary uses of limestone it is, of course, worthless but it should be valuable for agriculture as it has the same character as pulverized limestone.

The accompanying photograph (Plate IX) of the quarry of the Calcite Quarry Co. at Myerstown as seen from the crusher shows the method of quarrying and disposal of waste.

Steelton quarry.—The most extensive single quarry operation in the region is that of the Bethlehem Steel Co. at Steelton. This quarry has long been worked to obtain flux for the Steelton furnaces. It is well located for economical operation as the quarry is in the side of a hill facing the Susquehanna River. Without going lower than the river a quarry face averaging approximately 100 feet high has been obtained over the larger part of the quarry, which is more than a quarter of a mile long. The stone is quarried by breaking down 100,000 tons at a single blast. It is loaded into cars by steam shovels and hauled to the crushing plant where it is broken to blast furnace size. The furnaces are adjacent to the quarry.

The strata in this quarry are both folded and faulted but are much less cavernous than the limestones elsewhere in the valley. One small cavern has been encountered in which there is a small quantity of travertine or cave onyx.

The thickness of the overburden of clay and rotten limestone is decidedly variable as determined by numerous borings in addition to the sections exposed in the working face. The average thickness is probably about 12 to 15 feet but in many places the overburden exceeds 30 feet and in a few borings it was even more than 40 feet.

The composition of the stone varies from layer to layer and in the same layer in different parts of the quarry. However there are few places where the silica content is excessive. In the following table of analyses the average and also some of the unusual compositions are shown, the selection being made from scores of analyses available.

The stone in this quarry at Steelton would also be useful for other purposes although little has been used other than for flux. A few years ago a small quantity was sold for road metal.

PLATE IX.

Calcite Quarry Co. quarry, Myerstown, Lebanon County.

Analyses of Cambro-Ordovician limestone of Lebanon and Dauphin counties.

	1	2a	2b	3	4	5	6
$CaCO_3$	89.55	92.24	94.44	93.86	93.92	94.66	95.78
$MgCO_3$	5.22	3.46	.90	1.94	3.67	3.17	2.46
SiO_2	3.56	2.00	2.52	2.57	1.27	0.84	1.05
Al_2O_3	1.84	1.26	1.56	1.57	1.02	0.97	----------
Fe_2O_3	----------	.74	.55	----------	----------	----------	----------
S	----------	.046	.015	----------	----------	----------	----------
P	----------	.008	.005	----------	----------	0.004	----------

	7	8	9	10	11a	11b	11c
$CaCO_3$	94.20	70.50	71.27	73.20	59.06	41.93	66.70
$MgCO_3$	2.89	13.34	18.66	11.60	30.50	21.16	21.19
SiO_2	1.37	10.57	6.43	8.23	7.42	11.20	8.10
Al_2O_3 } Fe_2O_3	1.14	5.55	3.65	6.93	3.79	25.40	4.12

	12a	12b	12c	12d	13	14	15	16	17
$CaCO_3$	78.13	80.68	82.20	81.76	67.40	60.79	78.72	82.58	74.92
$MgCO_3$	8.37	10.12	3.96	6.58	22.93	34.44	17.60	11.49	17.49
SiO_2	8.70	5.77	10.10	7.28	6.48	3.12	1.85	3.56	3.54
Al_2O_3	1.94	2.13	1.58	1.97 }					
Fe_2O_3	2.20	1.96	1.65	1.73 }	3.15	1.82	1.95	2.25	4.02

1. Property of Ephraim Erb, 1¼ miles southwest of Richland. Average of 4 prospect samples. Analyses by Bethlehem Steel Co.

2. Upper portion of Cambro-Ordovician limestones, Millard quarry, Myerstown. a. Average of 209 cars shipped to Thomas Iron Co. during first half of 1920. b. Average of 180 cars shipped to Thomas Iron Co. during latter half of 1920. Analyses by Thomas Iron Co.

3. Ebbling quarry, East Myerstown. Analysis by Bethlehem Steel Co.

4. Bassler quarry, West Myerstown. Analysis by Bethlehem Steel Co.

5. Upper part of Cambro-Ordovician limestones, Calcite Quarry Co. 1½ miles west of Myerstown. Average of 9 analyses made by the Robesonia Iron Co. between 1913 and 1921.

6. Millard quarry 2 miles west of Myerstown. Average of 5 analyses of car load lots made by Midvale Steel and Ordnance Co.

7. Bethlehem Steel Co. property north of Prescott. Average of 59 diamond drill hole samples. Analysis by Bethlehem Steel Co.

8. Quarry of Cornwall Furnace Co., Lebanon. General quarry sample. Analysis by Bethlehem Steel Co.

9. Quarry of Cornwall Iron Co., South Lebanon.

10. Property of Anthracite Furnace Co. ½ mile northwest of Cornwall. Average of 4 prospect samples. Analysis by Bethlehem Steel Co.

11. Drill samples from south side of west end of mine at Cornwall Sept. 29, 1915. Analysis by Bethlehem Steel Co.

12. 4 samples of limestone from south side of Middle Hill, Cornwall mine, taken at intervals of 25 feet, Jan. 24, 1919. Analysis by Bethlehem Steel Co.

13. Reinhard quarry, southwest part of Lebanon. Average quarry sample. Analysis by Bethlehem Steel Co.

14. Lineaweaver quarry, West Lebanon. Average of 21 samples. Analysis by Bethlehem Steel Co.

15. Stanley quarry, 1½ miles west of Lebanon. General quarry sample. Analysis by Bethlehem Steel Co.

16. Kreidler quarry, Cleona. General quarry sample. Analysis by Bethlehem Steel Co.

17. Imboden quarry, ½ mile southwest of Cleona. General quarry sample. Analysis by Bethlehem Steel Co.

Analyses of Cambro-Ordovician limestone of Lebanon and Dauphin Counties—Continued.

	18	19	20	21	22	23a	23b	24
$CaCO_3$	84.76	81.54	95.26	96.06	81.10	84.37	95.67	82.69
$MgCO_3$	10.50	12.55	2.97	1.68	5.84	10.57	2.88	15.21
SiO_2	1.56	3.10	.93	1.03	8.92	2.20	1.09	1.81
Al_2O_3	3.22	2.83	.80	1.29	4.26	1.85	.72	1.04
Fe_2O_3	----	----	----	----	----	0.55	----	----
S	----	----	----	----	----	0.033	----	----
P	----	----	----	----	----	0.008	----	----

	25	26	27	28	29	30	31	32a	32b
$CaCO_3$	83.41	87.01	80.77	60.37	75.57	74.72	73.88	94.44	90.36
$MgCO_3$	13.72	10.11	9.99	37.85	19.29	21.42	21.51	3.89	7.59
SiO_2	2.00	1.98	7.86	2.36	4.54	3.02	3.66	2.02	1.96
Al_2O_3	1.24	.70	2.15	1.18	.85	----	1.28	.36	.33
Fe_2O_3	----	----	----	----	----	----	----	.30	.31

18. Annville Lime Co. (Deitzler) quarry, East Annville. General quarry sample. Analysis by Bethlehem Steel Co.

19. Sheffy and Mark quarry, east Annville. General quarry sample. Analysis by Bethlehem Steel Co.

20. Smith quarry, north Annville. General quarry sample. Analysis by Bethlehem Steel Co.

21. Batdorf and Forney quarry, northwest Annville. General quarry sample. Analysis by Bethlehem Steel Co.

22. Funk quarry, northwest Annville. General quarry sample. Analysis by Bethlehem Steel Co.

23. Millard quarries, Annville. a. Average of 3 cars shipped to Thomas Iron Co. during 1920. b. Average of 8 cars shipped to Steelton in 1917.

24. Quarry of Annville Quarry Co. 1 mile northwest of Palmyra. Average of 42 cars shipped to Steelton during 1917. Analysis by Bethlehem Steel Co.

25. Spring Creek Limestone Co. quarry, Swatara. Average of 60 cars shipped to Steelton during 1917. Analysis by Bethlehem Steel Co.

26. Bradley quarry, Swatara. Average of 22 cars shipped to Steelton during 1917. Analysis by Bethlehem Steel Co.

27. Abercash quarry, 1 mile east of Hummelstown. Average of 8 samples. Analysis by Bethlehem Steel Co.

28. Stover quarry, 2¼ miles southwest of Hummelstown. Average of 2 samples. Analysis by Bethlehem Steel Co.

29. Hocker quarry, 1 mile southeast of Steelton. Average of 9 samples. Analysis by Bethlehem Steel Co.

30. Cumbler property, ½ mile southeast of Steelton. Average of 14 diamond drill cores. Analyses by Bethlehem Steel Co.

31. Quarry of Bethlehem Steel Co., Steelton. Average of shipments during 1918. Analysis by Bethlehem Steel Co.

32. Upper part of Cambro-Ordovician limestones. J. T. Whitlock quarry, Paxtang. a. Average of 7 cars shipped in 1915. b. Average of 18 cars shipped in 1916.

CUMBERLAND AND FRANKLIN COUNTIES.

The Great Valley with its Cambrian and Ordovician limestones cuts across Cumberland and Franklin counties from the Susquehanna River to the Maryland line. The main band of limestones is 10 to 12 miles wide in some places. Due to complicated folding several detached limestone areas form the floor of subsidiary valleys.

Throughout these counties the soil cover is considerably thinner than in most of the other limestone areas of the State, and, as a consequence, outcrops are more numerous.

Division into Formations.

Stose* has subdivided the Cambro-Ordovician limestones of Franklin County into the following formations:

Ordovician

Chambersburg limestone. 100-750 feet thick.

"Thin-bedded tough dark limestone, usually very fossiliferous with irregular clayey partings giving rise to limestone "cobble" on weathering. Interbedded shale at the top in most places forms gradation into Martinsburg."

Stones River limestone. 675-1050 feet.

"Very pure, thin-bedded, even-grained. dove-colored limestone at top and bottom with some magnesian layers; granocrystalline gray fossiliferous limestone with thin layer of black blocky chert in middle."

Beckmantown limestone. 2300 feet.

"Thick-bedded, rather pure limestone in large part finely laminated, interbedded with magnesian beds and fine-grained pink to white marble; contains beds of oolite, fine conglomerate, chert nodules, and quartz geodes at several horizons and grading downward into blue limestone with hard siliceous laminae, coarse "edgewise" conglomerate, and purer fine-grained marble.

"Small rosette and "cauliflower" cherts at or near the top of the formation."

Cambrian.

Conococheague limestone. 1625 feet.

"Thin-bedded blue limestone finely banded by thin, hard siliceous, generally contorted laminae that weather in relief and finally disintegrate to slaty sandstone and shale fragments."

"Edgewise" conglomerate, chert, oolite, and limestone conglomerate containing quartz grains and weathering to porous sandstone, at the base."

Elbrook formation. 3000 feet.

"Gray to pale-blue shaly limestone and calcareous papery shale with some heavier limestone beds at the base and thick-bedded siliceous limestone in the middle."

Waynesboro formation. 1000± feet.

"Slabby gray calcareous sandstones or sandy limestones and hard slaty purple shale, with limestone and fine-grained white marble in middle. Large scoriaceous white chert heads and vein quartz in lower portion."

Tomstown limestone. 1000 feet.

"Massive and thin-bedded limestone, in part cherty and magnesian, with considerable shale and soft white clay at the base."

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*Geol. Atlas of the U. S.; Mercersburg-Chambersburg Folio No. 170 U. S. G. S., Washington, D. C. 1909.

Although recent maps showing the distribution of geologic formations of Cumberland County have not been prepared it is known that the same formations occur there.

Uses.

The Cambro-Ordovician limestones of Cumberland and Franklin counties have been quarried in scores of places for a wide variety of uses yet few large quarrying operations have been developed. Most of the material quarried has been used locally or in the adjoining counties.

The early uses of these limestones were for the manufacture of agricultural lime, as flux in the numerous iron blast furnaces that were located in the region when the local iron ore mines were in operation, and for the construction of buildings. Although they were fairly satisfactory for all of these purposes, in few places within the region is limestone being quarried at the present time for any of these industries. Nevertheless limestones of sufficiently desirable character may in time be much more fully utilized than at present.

In recent years the chief use for limestone quarried here has been as ballast, in the improvement of highways, and also as crushed rock in other construction.

Some quoted paragraphs following are taken from Stose's description of the areas included within the Mercersburg and Chambersburg quadrangles but they apply equally well to the entire limestone region of these two counties.

Lime and Flux.—"Lime is extensively used in this area for enriching the soil, and the various limestones are quarried for this purpose throughout both quadrangles. Much of the limestone, especially that of the Conococheague and lower formations, is very impure, usually containing a large percentage of magnesium carbonate and fine siliceous and argillaceous matter, but beds can be found almost anywhere that will yield lime suitable for local use as fertilizer. Lime is especially beneficial to the sandstone and shale soils, and kilns are consequently more numerous along the shale border. Much of the lime is burned in heaps in the field without permanent kilns. The Stones River limestone is the purest of the Shenandoah group and all the high grade lime is made from it."

In general the Stones River limestone lies near the northwest border of the limestone belt only a short distance from the overlying Martinsburg slates. Due to complex folding and faulting small areas are occasionally noted elsewhere.

The most extensive quarrying operation in the entire district at present is near Williamson, Franklin Co., where the J. E. Baker Co. has opened 3 quarries in the Stones River formation. One quarry at the south edge of town has been worked extensively but has now been worked almost to the property lines and will be abandoned. Some stone is still quarried and burned for lime for local use. Two other quarries along the railroad about ½ mile north of town have been opened but only one was being worked at the time of our visit. The stone is fine-grained and uniform. An average analysis furnished by the company is as follows:

Analysis of limestone in Baker quarry near Williamson, Franklin County.

$CaCO_3$	95.60
$MgCO_3$	2.80
SiO_2	.90
Al_2O_3, Fe_2O_3	.70

The product of the Williamson quarries is chiefly used in blast furnaces and plate manufacture.

"A sample from the Stones River limestone near Mercersburg showed on analysis 96.4 per cent of calcium carbonate. Although these pure beds are not so thick as those at Martinsburg, W. Va. where the rock is quarried on an enormous scale for shipment as flux to the iron furnaces of Pittsburgh, the analyses compare favorably. Three samples of Stones River limestone from the Martinsburg quarries contain 93.2, 97.7, and 98.1 per cent of calcium carbonate.

"The outcrop of the Stones River formation is shown on the areal geology maps of the U. S. G. S. Geologic Folio, No. 170 and rock suitable for lime production can be obtained at most places within its area. Numerous quarries are located in the belts between Chambersburg and Greencastle adjacent to the shale lands, and a large industry has been developed in the Rocky Spring cove, which is surrounded by shale farm lands. The Stones River limestone is exceptionally pure and thick bedded in this locality and the large quarry 1 mile north of Beautiful runs six kilns.

"Certain beds in the Chambersburg and Beekmantown formations are also fairly pure and make a lime of good grade. Large quarries and kilns in the Beekmantown are located at Stonehenge and Stoufferstown, east of Chambersburg. Exceptionally pure beds in the Chambersburg limestone occur at Fort London and in the vicinity of Blue Spring, southwest of Mercersburg. A sample from the Chambersburg limestone near Mercersburg showed an analysis 93.2 per cent of calcium carbonate and only 0.07 per cent of magnesium carbonate, the rest being largely insoluble impurities."

"A large number of beds in the Shenandoah group, especially in portions of the Tomstown and Beekmantown limestones, contain a high percentage of magnesium carbonate. Beds ranging from 25 to 40 per cent in magnesium carbonate alternate with almost pure limestone containing 1.4 to 3 per cent, but by selection in quarrying the highly magnesian layers can be segregated."

At Newville a quarry has been opened mainly for road-building material but certain strata, somewhat purer than the average, are burned for agricultural lime. The average stone is said to contain about 82.7 per cent of calcium carbonate.

The Walton quarry along the Susquehanna River opposite the lower portion of Harrisburg has likewise been worked in recent years for road and concrete material mainly but some is burned for lime and some used for flux. In Part I of this report, the variation in the chemical composition of the stone from this quarry is discussed. An average of 11 samples collected and analyzed by the Bethlehem Steel Co. gave the following results:

Analysis of limestone from Walton quarry, near Lemoyne.

$CaCO_3$	87.13
$MgCO_3$	10.32
SiO_2	3.00
$Al_2O_3+Fe_2O_3$	.87

Cement.—"Certain black limestones in the transition beds at the base of the Martinsburg formation are probably suitable for the manufacture of natural cement. These beds are generally too thin and too much mixed with the shale to be economically used for this purpose, but they thicken toward the west, and beyond Mercersburg, especially in the eastern part of McConnellsburg Cove, individual beds are 1 foot thick and the more massive portion aggregates 6 to 8 feet in thickness. An analysis of a sample of rock from this horizon in the Rocky Spring cove is as follows:

"*Analysis of black limestone at base of Martinsburg formation in Rocky Spring cove.*

[W. T. Schaller, analyst.]

$CaCO_3$	68.82
$MgCO_3$	.20
$FeCO_3$	1.34
Fe_2O_3	.55
Al_2O_3	2.82
SiO_2 etc (insoluble)	22.93
	96.66

"This rock differs from the best natural cements in its low percentage of $MgCO_3$, which may vary in the different beds, and the use of the rock for cement purposes can be determined only by a number of analyses and practical cement tests.

"Better cement can be made by mixing pure limestone with shale, the proportion of each to be determined by careful analysis of the constituents and thorough test of the product. The purer beds in the Stones River, Chambersburg, and Beekmantown limestones are suitable for this purpose, and shale can be procured from the adjacent shale belts. Cement could be commercially manufactured at almost any place in the Stones River limestone areas not too distant from the Martinsburg shale and convenient to the railroad. No plant is established in this area at present."

At one time natural cement was made from some of the limestones near Scotland as recorded in Report M3 of the Second Geological Survey of Pennsylvania, p. 82.

Analysis of limestone near Scotland, Franklin County.

$CaCO_3$	47.375
$MgCO_3$	15.581
SiO_2	29.640
$Al_2O_3+Fe_2O_3$	6.760

Building Stone.—"Stone for local building purposes is plentiful in this area, but none suitable for shipment is known. Limestone of convenient thickness for quarrying can be obtained in most portions of the Shenandoah group, and it makes very enduring structures, as attested by the old stone dwellings and arched bridges across the streams throughout the valley. At present it is used very little for building stone, except in foundations, walls, bridge piers, and rubble fences."

Marble.—"Marble for building or ornamental purposes has not been quarried in this area, but several beds of possible value have been seen. The most attractive bed is a pink marble irregularly veined with green that occurs near the base of the Beekmantown. Several of the purer white limestones of the Beekmantown are finely crystalline marble and have a faint pink tint, but 1½ miles southeast of the village of Clay Hill, the marble has unusually good color. Specimens collected here, although from the surface and considerably fractured, acquire a fine polish. If the color is found to continue with depth and sufficiently large blocks can be quarried, this marble may prove to be of commercial importance.

"Other beds of marble, probably of little commercial value, observed in the area, are as follows: A fine-grained milk-white marble, badly sheeted, in the Waynesboro formation 1 mile northeast of Waynesboro; a coarse mottled reddish variety in the Conococheague limestone in the vicinity of Scotland; a black conglomerate with reddish pebbles near the base of the Beekmantown, seen in both the Chambersburg and the Mercersburg quadrangles; light-colored fine conglomerates and oolites in the Chambersburg and Beekmantown formations of both quadrangles; and layers of concentric, wavy Cryptozoon at the base of the Conococheague near Falling Spring and Zentmyer that make "bull's-eye" marble when polished parallel to the lamination."

Crushed stone.—As in other portions of the State where the limestones of the same age are found, the Cambro-Ordovician limestones have been extensively worked for road ballast and for concrete within recent years. Most of the improved roads of the counties pass through the limestone areas and consequently suitable material was near at hand. With the exception of the most pure and the decidedly shaly limestones practically all the other limestones are suitable for these uses. With so wide a distribution of satisfactory stone for concrete and ballast it has been possible to obtain good quarry sites near the towns. The principal quarries for crushed stone are near Waynesboro, Chambersburg, Shippensburg, Newville, and New Cumberland.

In the Annual Report of the Second Geological Survey of Pennsylvania for 1886, Part IV, pp. 1519-1522, d'Invilliers gives descriptions of several limestone quarries in Cumberland and Franklin counties, most of which have long since been abandoned.

Analyses of Cambro-Ordovician limestones of Cumberland and Franklin counties.

	1	2	3	4	5	6a	6b
$CaCO_3$	72.321	86.357	89.178	54.393	51.743	97.321	67.257
$MgCO_3$	20.591	5.236	.961	42.694	43.436	1.286	30.202
SiO_2	2.310	8.410	8.840	2.160	4.090	.980	1.760
Al_2O_3	.083	.571	.806	.941	.222	.260	.760
Fe_2O_3	4.420						
P	.047	.013	.050	.013	.013	.005	.007

1. Limestone at Pine Grove Furnace.
2. Craighead quarry, 2 miles north of Mt. Holly.
3. Limestone from Mine No. 3, Mont Alto Iron Co., Mt. Alto.
4. Limestone from Mine No. 4, Mont Alto Iron Co., Mt. Alto.
5. Shiery quarry, 1½ miles northeast of Mont Alto.
6. S. Z. Hawbecker's quarry, Williamson. a. Best quality stone. b. Poorest quality stone.

All of the above analyses are taken from Report M3 of the Second Geological Survey of Pa. pp. 80-81.

LYCOMING AND CLINTON COUNTIES.

In the southern part of Lycoming and Clinton counties there are three fine examples of anticlinal valleys. These are Mosquito Valley (also known as Jacks Hollow in Armstrong Township, Lycoming County), Nippenose Valley, mainly included within Lycoming County but extending a short distance into Clinton County; and Sugar Valley in the extreme southern part of Clinton County. In addition to these a portion of the larger Nittany Valley extends into Clinton County. Mosquito, Nippenose, and Nittany valleys are in a straight line and are part of the same anticlinal fold. The axis itself is wavy and the limestones were brought sufficiently near the surface only in certain portions to permit their solution and the formation of valleys. The uplift was much greater in the Nittany Valley than in the Nippenose and Mosquito valleys. Only the upper beds or Ordovician strata are exposed in the eastern valleys but a great thickness of Cambrian beds is exposed in Nittany Valley. Erosion has exposed the Cambro-Ordovician limestones in the central portions of all of these valleys. The strata dip away from the axes of the folds and disappear beneath the Ordovician slates that form a continuous band about the valleys. The slates in turn dip toward the sides of the valleys and pass beneath the younger hard resistant sandstones that form the high bounding valley walls. The only easy access to these valleys is along the streams that drain them and that have cut deep narrow gaps in the enclosing barriers.

No railroads enter Mosquito, Nippenose, or Sugar valleys. The soil is fertile and some excellent farms are to be noted in them.

Mosquito Valley.

Mosquito Valley lies about 3 miles southwest of Williamsport. It is a symmetrical oval-shaped valley, enclosed by mountains rising about 800 to 900 feet above the floor of the valley. The limestones are exposed at the surface over an area about 2 miles long and half a mile wide. They have been quarried in a few places for local use.

In the report on Lycoming and Sullivan counties (GG) of the Second Geological Survey of Pennsylvania (pp. 77-78) there is the following description of a black marble quarry formerly worked.

"Near the east end of Mosquito valley a marble quarry has been opened. It yielded the fossil named *Calymene senaria.*"

"The rock is a black limestone; quarries out in large blocks and takes a handsome polish. It is reported however not to stand exposure, but splinters up on weathering. This would render it useless for any outside work, but might still leave it of value for inside decorations."

"When the quarry was examined (in 1875,) the works were in operation; they had 1 gangsaw, capacity 100 tiles per diem; these tiles usually 12″ x 12″ x 1″: the tiles going to Philadelphia and the stone to Philadelphia or Washington.

"All of the marble is dark colored, very slightly fossiliferous, regular in bedding and works easily.

Surface bench, in small layers, 1″ to 2″ and up to 1′,	10′ 0″
Middle bench, in regular layers from 2′ to 1′ thick	20 0
Lower bench, massive and hard, but no stone from it yet shipped	6
Total	36′ 0″

"The dip of these rocks is north 4°; the quarry is about on the crest of the anticlinal, and the dip is simply the dying gently of that anticlinal northeastward."

"Of the above 36 feet of black marble much proved shelly on quarrying, and split into pieces; a considerable part however coming out in handsome blocks."

"It is reported to burn to an excellent white lime."

"There are some curious soft and rotten layers of stone lying between the firm and hard marble layers thus:

Hard marble	1 ′
Soft decomposed marble	—
Hard marble	1½ ′

the underlying and overlying hard rocks being perfect and unbroken so far as traced."

This quarry was visited by the writer in 1921. The excavations and refuse heaps indicate that a considerable quantity of stone was taken from the locality. It is said that the stone acquired a bad reputation because of the ease with which it disintegrated on exposure to the air, a reputation that it probably deserves as shown by the pieces of rotten stone now lying about the quarry openings. For interior use, however, it appears to be satisfactory. A table top and a carved pedestal seen in a home in Duboistown and said to be about 50 years old were in good condition and very attractive. The openings were on the steep slope of a hill. It appears that considerable difficulty was experienced in locating satisfactory stone without removing an unnecessarily large amount of worthless material.

Nippenose Valley.

Nippenose Valley lying about 5 miles south of Jersey Shore is 10 to 11 miles long and 3 to 3½ miles wide. It is entirely surrounded by a mountainous wall of sandstone through which the stream that carries its drainage waters into the Susquehanna River has cut a gap.

The soil of the valley, although comparatively thin in most places, is fertile and there are many fine farms in the region. The limestones are honey-combed with subterranean caverns and most of the drainage is by underground channels. The stream that carries the water out of the valley emerges only a short distance from the gap. Sink holes are numerous throughout the valley.

In a number of places the limestones have been quarried for agricultural lime and for highway construction. A black impure shaly limestone has been quarried as a mineral pigment at Millport and near Davidson. It is ground for shipment at a mill located within the gap. This rock seems to belong to the same horizon as the black marble of the Mosquito Valley, described on an earlier page. In both cases the black stone is close to the contact with the overlying Ordovician black slates.

The most extensive quarrying operation in recent years has been developed near the gap. The quarry face is about 75 feet high and 400 feet long. At the extreme western end the rock is dark and somewhat argillaceous but more massive, harder and purer in the eastern portion. Several small caves have been discovered in the process of quarrying and a fairly large underground stream located. The stone is burned for agricultural lime for local use. A small quarry on the Collomsville road has been worked for road metal. The rock breaks with a conchoidal fracture. At the eastern edge of the village of Collomsville a small quarry is worked to supply stone for 3 lime kilns. The rock is gnarly in character.

In the report of the First Geological Survey of the State[27] it is stated that "at Bixler's tavern in the east end of the valley there is a so-called 'marble quarry', which affords a hard solid dark-blue limestone, variegated by thin veins and specks of yellow and sometimes white, spar, and susceptible of a good polish. Its dip is 15°S. 20°E. The same rock might be traced through the valley near its center line."

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[27] Rogers, H. D., The geology of Pennsylvania, Vol. 1, p. 490, 1858.

Platt[28] gives the following description of a locality where limestone was formerly quarried and ground for agricultural use.

"In the southwest part of the Nippenose Valley, just across the Lycoming county line and therefore in Clinton county, a so-called plaster is opened on the Joseph Wilsham place.

"The rock dips to the northward 7° or 8°, and in appearance is a bluish limestone, with much calcite, and very fossiliferous in layers.

"This rock has been ground up and used as a plaster, and indeed is now used for that purpose. It sells readily to the county around, in considerable quantities, at prices but little below the Cayuga or Nova Scotia plaster. Mr. Metzger and others have a mill near the quarry.

"A specimen of the "plaster" rock and of the ground "plaster" were forwarded to the Laboratory of the Survey, and on analysis were found to have less than one per cent of soluble sulphate of lime. (A. S. McCreath.):

Silicic acid	2.660
Carbonate of lime	95.071
Carbonate of magnesia	1.044
Carbonate of maganese	trace
Phosphate of lime	trace
Carbonate of iron	.261
Sulphate of lime	.744
Organic matter and water	.220
	100.000

"Geologically the horizon of this so-called plaster rock is about 500± feet below the bottom of the slates of III.

"The analysis shows that the rock is in no sense a plaster rock, but simply a limestone."

Sugar Valley.

In the course of the present investigation Sugar Valley was not visited. The following brief description is taken from Report G4 of the Second Geological Survey of Pennsylvania.[29]

"This beautiful and fertile canoe-shaped limestone valley is from one to one mile and three-quarters wide and about seventeen miles long.

"It is surrounded on all sides by the mountains formed by the outcrop of No. IV,—the Oneida and Medina sandstones. Between these and the limestone floor of the valley is a band of slaty and shaly measures (No. III) forming the mountain flank. Very fair land often results from a disintegration of these measures when free from the debris of mountain sandstone with which they are usually covered.

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[28] Platt, Franklin, The geology of Lycoming and Sullivan Counties: Pennsylvania Second Geol. Survey, Rept. GG, pp. 80-81, 1880.

[29] Chance, H. M., The geology of Clinton County: Pennsylvania Second Geol. Survey. Rept. G4, pp. 36-38, 1880.

"The anticlinal which elevates the valley-forming limestones of Sugar valley gently dies away at both the eastern and western ends of the valley. The greatest thickness of limestone is therefore brought above water level near the centre of the valley."

"The drainage of Sugar Valley is not nearly so irregular as that of Nippenose and Nittany. Sink-holes and underground water courses are more rare. The whole valley is drained by Big Fishing creek which rising at the east end of the valley flows westwardly through its whole length, keeping near the centre of the valley and finally flows into Nittany valley through the sharply cut and tortuous gap at Washington furnace."

"About three and a half miles from the west end, upon the main road up the valley, a pale blue fetid limestone occurs, speckled with yellow spar like the Nippenose "marble." It dips 20°; sandy limestone in the creek, two miles further east dips 15° north. The anticlinal becomes more regular near the middle of the valley. In Kleckner's Gap the dip is 30° north.

"The margin of the limestone recedes a little farther from the foot of the mountain east of Kleckner's Gap. At the furnace there is a quarry of massive strata dipping 10° N. 20° E., marking the decline of the anticlinal in that direction."

Nittany Valley.

That portion of the Nittany Valley lying within Clinton County is about 12 miles long and 4 wide, nearly all of which is underlain by the Cambro-Ordovician limestones. Inasmuch as the Nittany Valley limestones are described somewhat fully under "Centre County" it is unnecessary to describe them in detail here. The formations described there extend into Clinton County.

The most extensive quarrying in the region is by the Bellefonte Lime and Stone Co. at Salona, 2 miles southwest of Salona, where crushed rock for highway construction and railroad ballast is prepared. Two quarries have been opened there and later connected by a tunnel. Several types of stone are exposed in the quarry. The Bellefonte high grade stone is present although the major portion of the stone quarried is harder, darker in color and less pure.

CENTRE COUNTY.

The Cambro-Ordovician limestones form the surface rocks of approximately one-fourth of Centre County and underlie some of the most prosperous agricultural sections of the State. Within the county very little farming is done except in these fertile limestone valleys.

Division into formations.

The limestones of the region have been studied in detail by E. S. Moore and others who have established the following formations.

	Feet
Ordovician System.	
Reedsville (Hudson River or Martinsburg) shales	
Trenton limestone. Highly fossiliferous thin-bedded limestone and black to brown shale	791
Black River group. This group includes the Rodman and Lowville limestones, which are usually pure, blue to gray rocks. The Lowville contains the important "quarry rock"	182
Chazy (Carlim and Pamelia) limestone. Bluish limestone	260
Beekmantown series.	
Bellefonte dolomite. Dolomitic strata with a thin bed of sandstone	1911
Axemann limestone. Pure fossiliferous limestone, dolomitic limestone, oölitic limestone, and reddish limestone conglomerate	480
Nittany dolomite. Coarse, light to dark dolomite with much chert in lower portions	1206
Stonehenge group. Limestone, edgewise conglomerate, limestone conglomerate and calcareous shales	633
Cambrian System.	
Ore Hill formation. Cherty dolomite and siliceous oölite	150
Gatesburg formation. Interbedded dolomite and sandstone	800
Warrior formation. Limestone, oölitic limestone, and beds of shale	688
Total	7101

Geologic Structure.

The structure of all the Cambro-Ordovician limestone valleys of the central part of the State is very much the same. After the deposition of these and overlying strata that outcrop in Bald Eagle Mountain in the Alleghany Mountains the whole region was thrown into great longitudinal folds, approximately parallel, with a northeast-southwest trend. Erosion then became active and after many thousands of years the ridges were obliterated and a broad low-lying plain resulted in which there was little or no difference in elevation based on the character of the rocks.

A second uplift again started erosion and the wearing away of the least resistant rocks, the limestones, soon formed the valleys. It so happens that these limestones are the oldest rocks of the region and thus constituted the cores of the old ridges, or anticlinal folds. Above the centers of these limestone valleys, where, consequently, there has been the greatest amount of material removed, it is estimated that a restoration of these old folds would give us mountains over 20,000 feet in height, possibly as much as 25,000 to 30,000 feet. It is improbable that such mountains ever did exist as the uplift was a slow process, and erosion was wearing down the elevated portions simultaneously, yet mountains of very considerable height must have existed at the close of the folding.

By this major structure that is everywhere prominent, the youngest limestones are found at the edges of the valleys where they dip beneath the shales and sandstones that constitute the ridges. In general the strata dip steeply on the northwest sides of the valleys and more gently on the southeast sides, which seems to indicate that the compressive movement proceeded from the southeast toward the northwest.

In addition to the major structure, there are occasional subordinate crumples or folds that are roughly parallel to the main folds. Also the strata have been broken in places and one side offset with reference to the other. Offsets or faults of this kind have been determined in several places. In one place the displacement is about a quarter of a mile.

Nittany Valley, with maximum width of about 9 miles, is the most important of these anticlinal valleys. Brush Valley and Penns Valley produced by minor folds are off-shoots of this main valley. Nippenose Valley, the larger portion of which is in Lycoming County, although separated from Nittany Valley by more highly elevated portions of sandstone strata, is in line with it and constitutes a part of the same fold. The intervening area was not uplifted quite as high so was not worn down in the great erosion period sufficiently to uncover the limestones. Sugar Valley, which is likewise detached from Nittany Valley, has been produced by the erosion of limestone elevated by a small distinct fold.

Uses.

As indicated in the table on a preceding page, Centre County contains a great variety of limestones adapted to almost all the uses to which limestones have been put. Scores of quarries have been opened throughout the county to provide building material, mainly for foundations, walls, etc., for stone to be burned for agricultural lime, for road metal and concrete, and for flux. As in other parts of the State local burning of lime has almost passed away and the small kilns are in ruins.

During the period when the numerous limonite iron ore mines were in active operation limestones were quarried extensively in the vicinity of the furnaces for flux. These quarries were abandoned when the iron industry died and the only ones that have continued to furnish flux are those that have low-silica stone and are favored with good shipping facilities.

The increased demand for crushed stone for road metal and concrete has resulted in the opening of many quarries but in most cases only to supply rather local needs. Nearly all the limestones of the county will meet the specifications of the State Highway Department.

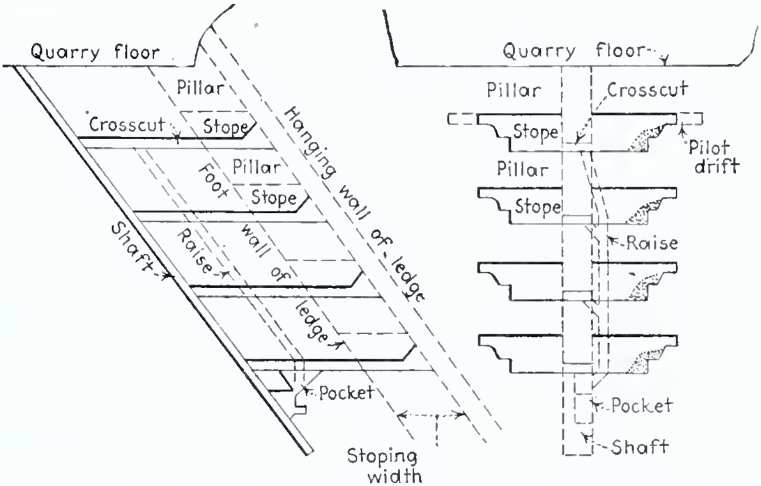
In recent years the manufacture of high grade lime in the county has developed rapidly. This has been possible because of the existence of a band of limestone within the Lowville member of the Black River group that is in many respects the best limestone within the State. Although it has been recognized in adjoining counties, it presents its best phase in the vicinity of Bellefonte, where it also seems to be thickest. It averages over 98 per cent $CaCO_3$, almost 1 per cent $MgCO_3$, the balance SiO_2, Al_2O_3, and Fe_2O_3. At Bellefonte the best stone is 77 feet thick but it thins in both directions and in some places throughout the valley no stone of this character has been found at this horizon.

Bellefonte ledge.—In the vicinity of Bellefonte the best quarry stone lies beneath the thin, rather siliceous, shaly beds of the Trenton limestone that is of little use except for road metal. The good stone, commonly called the "Bellefonte ledge," is a dark to light dove-colored compact limestone that contains in spots numerous white calcite crystals that sparkle on the freshly broken surface. The rock breaks with a prominent conchoidal fracture. Just west of the Buffalo Run road at Bellefonte the stratum dips about 52° to the north but at depth the dip increases to 63°. East of the road it is approximately vertical at one place. Beneath the Bellefonte ledge there is 60 feet of darker stone that is slightly higher in silica and is sold for furnace flux as it is too impure for the manufacture of chemical lime. Beneath the furnace stone is a band of blue stone that is somewhat gnarly on a fractured surface and so impure that it is valuable only for road metal and concrete.

At times the demand is such that all of these bands can be worked but there is usually less demand for the fluxing stone and the road metal. For the latter use there is keen competition as many other quarries can supply this grade. The companies operating in the region have therefore largely confined their attention to the ledge of the best stone. The bulk of this is burned and shipped as lump lime or pulverized raw lime or is hydrated at the plant. Some of the limestone is pulverized raw for glass manufacture and for fertilizing purposes.

The American Lime and Stone Co. (now affiliated with the Charles Warner Co.) operates 12 quarries in this band in the vicinity of Bellefonte, the most westerly of which lies just north of Briarly. The Chemical Lime Co. and the Center County Lime Co. are operating properties in the same band between plants of the American Lime and Stone Co. Across the valley, about 1 mile southeast of Pleasant Gap, are the White Rock quarries where the high grade stone dips toward Nittany Mountain. The ledge is about 40 feet thick and is overlain by about 45 feet of massive blue stone, also a part of the Black River group, that is sold for flux. This is capped by the shaly fossiliferous Trenton beds that showed a thickness of 5 to 10 feet at the top of the quarry face at the time of our visit.

The superior quality of the Bellefonte ledge makes it possible to work the beds even at costs greater than are necessitated in ordinary quarry operations. There is a limit to which the open cut quarry can be operated with safety with the overlying poor stone left standing and this limit having been about reached the American Lime and Stone Co. has sunk a 390-foot incline shaft at one of their quarries and is mining the stone (see figure 5). The shrinkage stope method is now being employed. No doubt there will be other operations of this kind in the future.[30]



Section through Shaft and Crosscuts

Section through Stopes

Figure 5. Plan of underground work, American Lime and Stone Co., Bellefonte.

Formerly companies searching in the region for the Bellefonte ledge have not only been concerned with the location of these beds of high grade stone but have had to regard their situation with reference to economical quarrying. In all probability there can be found some place where the overburden of clay is too great for open cut quarrying but where underground mining may be pursued with profit if the mine of the American Lime and Stone Co. proves as successful as is anticipated.

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[30] This operation and also the plant equipment of the American Lime and Stone Co. at Bellefonte are described in detail in the issues of Rock Products for June 3, 1922, pp. 32-35, June 17, 1922, pp. 59-68, Mar. 24, 1923, p. 35, and Sept. 6, 1924, pp. 47-49.

The Cambria Steel Co. made many examinations of the limestones of Centre County a few years ago in their endeavor to locate deposits of high grade fluxing stone. They finally acquired a property a short distance south of Millheim where a quarry has been opened. Rock from two drill holes was analyzed for silica alone, as follows:

Silica in limestone near Millheim, Centre County.

East of Elk Creek		West of Elk Creek	
Silica Per cent	Thickness Feet	Silica Per cent	Thickness Feet
8	50	8	75
3.24	25	3.65	20
0.77	80	1.95	90
3.4	30	5.83	25
7.0	20	2.6	50
2.7	50	7	?
7	?		

Sugar Valley was examined and near the western end some very low silica limestone was found that might be worked with profit if a railroad entered the valley.

In the vicinity of Spring Mills, both east and west of the village, there is some fairly low silica stone and also about 2 miles slightly north of east of Colburn.

The Oak Hall Lime and Stone Co. has a quarry about half a mile northwest of Oak Hall. Fluxing stone is shipped to the Cambria, Carnegie, and McKinney steel companies, the American Manganese Co., and the Punxsutawney and Emporia iron companies. The fluxing stone that is worked is about 100 feet thick and dips about 45°N. It is very dark in color. It is overlain by thin-bedded shaly and fossiliferous Trenton strata and underlain by a somewhat lighter-colored siliceous stone that has been quarried to a slight extent for building purposes. The Bellefonte ledge of high-grade limestone seems to be absent.

Analyses of Cambro-Ordovician limestones of Centre County.

	1.	2.	3.	4a.	4b.	4c.	4d.
$CaCO_3$	97.890	98.322	97.532	98.03	98.05	98.00	93.45
$MgCO_3$	1.285	1.170	1.210	0.80	0.79	0.96	2.19
SiO_2	----	----	----	0.44	0.47	0.86	1.75
Al_2O_3 } Fe_2O_3 }	0.263	0.520	0.377	0.17	0.15	0.14	0.87
Insoluble	0.540	0.390	0.815	----	----	----	----

	5a.	5b.	6a.	6b.
$CaCO_3$	94.17 to 95.67	94.63	87.39 to 95.89	93.21
$MgCO_3$	1.42 to 3.17	2.43	1.08 to 8.10	3.15
SiO_2	0.80 to 2.53	1.23	0.40 to 4.00	1.87
Al_2O_3 } Fe_2O_3 }	0.76 to 1.48	1.24	0.56 to 1.50	0.94
S	0.02 to 0.09	0.03	0.03 to 0.16	0.06
P	0.033 to 0.06	0.005	0.003 to 0.011	0.006

1. Shortlidge quarry, near Bellefonte. Upper bed. Hard and compact; seamed with calcite; pearl gray, with conchoidal fracture. (MM. p. 307).

2. Shortlidge quarry, middle bed. Very hard and compact; fine grained; seamed with calcite; pearl gray, with conchoidal fracture (MM p. 307).

3. Shortlidge quarry, lower bed. Hard and compact; mottled with calcite; pearl gray, with conchoidal fracture (MM p. 307).

4. White Rock quarries, 1 mile southeast of Pleasant Gap. a, b, and c, high grade stone for lime; d, fluxing stone. Analyses by Company.

5. Samples from roadside exposure about 2 miles north of east of Colburn. 8 samples analyzed. a, range, b, average. Analyzed by Cambria Steel Co.

6. Samples collected at random at Spring Mills and both east and west of there, exact location not known. 14 samples analyzed. a, range; b, average. Analyzed by H. A. Hosmer, Cambria Steel Co.

BLAIR AND HUNTINGDON COUNTIES.

The limestone belt of Centre County continues to the southwest into Huntingdon and Blair counties with little change in character.

The part that lies northeast of Little Juniata River forms part of the Nittany Valley. South of this stream the limestone belt forks. The western fork terminates about 10 miles to the southwest and is called Sinking Valley. The eastern fork extends in a parallel direction through Huntingdon and Blair counties into Bedford County. This limestone valley north of Williamsburg is designated Canoe Valley and the south extension, Morrison Cove. The narrow Black Log Valley containing Cambro-Ordovician limestones lies southeast of Orbisonia, between Black Log and Shade mountains, and extends northeast a short distance into Juniata County. Several valleys underlain by Helderberg limestones will be described in a later chapter.

As in Centre County the limestones occupy anticlinal valleys, that is, they mark the position of ridges long since removed by erosion. The sharp mountain ridges that now enclose the present valleys owe their greater altitude solely to the more resistant rocks that compose them.

Division into Formations.

Until recently the Cambro-Ordovician rocks of this section were not differentiated into separate formations. Charles Butts has proposed the following classification.[31]

Ordovician System.

Reedsville (Martinsburg, Hudson River) shale overlies the limestones.

	Feet
Trenton limestone. Thin-bedded black limestones weathering with a gray film on surface. Sparsely fossiliferous	320
Rodman limestone. Dark crystalline limestone weathering with a rough granulated surface; very characteristic and persistent. Fossiliferous. Upper Black River Group	30
Lowville limestone. Dark, thick-bedded, pure limestone, glassy to fine-grained. Extensively quarried for flux. Lower Black River Group	180
Carlim limestone. Dark fine-grained limestone, extensively quarried for flux. Fossils scarce except in impure Lemont argillaceous limestone member. Lemont member not quarried	180
Bellefonte dolomite. Thick-bedded dolomite yielding much dense chert. Fossils scarce	1,000
Axemann limestone. Thin-bedded blue limestone with dolomite layers. Fossils	100
Nittany dolomite. Thick-bedded, cherty dolomite. Fossils but not abundant	1,000

Cambrian System.

Larke dolomite. Thick-bedded, coarse, steely blue dolomite	250
Mines dolomite. Cherty dolomite, oölitic, yields much oölitic and platy scoriaceous chert. *Cryptozoon*, 2 species common	250
Gatesburg formation. Thick-bedded, steely blue, coarsely crystalline dolomite with many interbedded quartzite layers up to 10 feet thick, surface deeply covered with sand and strewn with quartzite boulders. Considerable siliceous oölite. Ore Hill limestone member, thin-bedded, blue limestone; several species of trilobites. Stacy dolomite member coarse, thick-bedded, steely blue, but without quartzite	1,750

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[31] Butts, Charles, Geologic section of Blair and Huntingdon Counties, central Pennsylvania: Amer. Jour. Sci., 4th ser., vol. 46, pp. 523-537, 1918.

Cambrian System—Continued.

Warrior limestone. Thick and thin-bedded, blue limestone with thin siliceous shaly layers or partings. A few thin quartzite layers and an occasional bed of limestone full of large well-rounded quartz grains. Some oölite. *Cryptozoon* common. Several species of trilobites	250
Pleasant Hill limestone. Thick-bedded limestone at top, fossils. Argillaceous thin-bedded limestone at bottom weathering to shale	600
Waynesboro formation. Sandstone, conglomerate, and red and greenish shale. Underlies the basal limestones	250+

In the classification Butts correlates the Bellefonte dolomite, Axemann limestone, and Nittany dolomite with the Beekmantown formation. He also places the Larke dolomite, the Mines dolomite, and the Gatesburg formation in the Ozarkian system, a usage that is not followed in this report.

Quarries.

In Blair and Huntingdon counties the Cambro-Ordovician limestones have been quarried in a small way in scores, perhaps hundreds, of places. For building foundations, for crushed stone, and for agricultural lime for local consumption almost any of the limestones described above might be used; indeed have been used. In the past when numerous small furnaces in the region were utilizing local ores little attention was given to the amount of silica present in the limestones; the proximity of the quarry to the furnace was more important, and some rather high silica limestones were used for flux.

The improvement in transportation facilities, the centralization of the iron and steel industry of the State in a few places where large plants have been established, and likewise the change in the lime industry by which the small operators have quit and firms with superior stone have enlarged their plants, have caused the abandonment of most of the small quarries and the development of a smaller number of large operations engaged in quarrying high grade limestones for flux and for lime. Opposed to this trend is the endeavor of the State Highway Department to use local stone so far as possible in building roads. This causes the opening of small local quarries for temporary use. In general, however, road metal and crushed stone for concrete are likewise obtained from the large quarries mainly worked for flux and for lime, as the small sizes produced in quarrying and crushing are useless for these purposes and can only be sold for crushed stone. Necessarily the cost of operation is also less in a large, well-equipped quarry so that the small quarry can compete only where it is so located with respect to the road under construction that a long and expensive haul is obviated.

A study of the classification table (pages 154-155) readily shows that the best grade stones are found in the upper part of the column. Practically every large operation confines its quarrying to these strata above the Bellefonte dolomite.

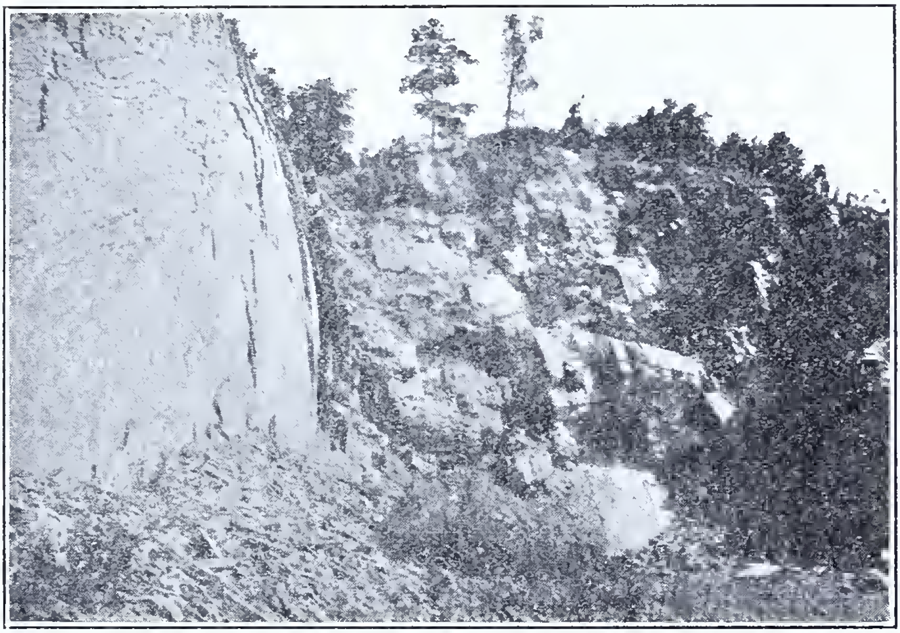
The anticlinal structure thus brings the stone of good quality at the sides of the valleys where the strata dip beneath the shales and sandstones of the ridges. The only exceptions to this rule are where the strata have been broken and displaced by a fault or where a subordinate syncline (downward fold) brings the upper beds down in the center of the valley. An example of this latter type of structure is seen in the quarry at Union Furnace in the Little Juniata River Valley where the upper limestone beds are present about midway of the broad limestone valley through which the stream has cut its course.

Tyrone.—About two miles east of Tyrone, on the southeast flank of Bald Eagle Mountain there are two quarries where the Rodman, Lowville, and Carlim limestones have been worked. One of these is the Tyrone Forge quarry of the American Lime and Stone Co., and the other is operated by the Pittsburgh Limestone Co. on property leased from the former company. In the former quarry the strata are slightly overturned and dip from 85° to 87°S.E. The quarry opening is narrow and the west face is formed by the Trenton limestones that make a sheer wall about 160 feet high. The company uses the larger blocks for the manufacture of agricultural and chemical lime and sells the spalls for flux. The other quarry is worked primarily for flux. The high grade limestone ledge (Bellefonte ledge) so extensively quarried at the same horizon near Bellefonte can be recognized in these quarries but it is thinner and the stone is also somewhat less pure. A fault in the Carlim limestone and the character of the sheer wall are shown in the accompanying photographs (Plate X).

At Birmingham the Cambria Steel Co. operated a quarry from 1893 to 1895 and shipped large quantities of fluxing stone. The quarry was finally abandoned because of the high silica. Analyses are given on a later page.

Union Furnace.—At Union Furnace the American Lime and Stone Co. operates 3 quarries. The beds exposed in the vicinity form a syncline. Quarries 1 and 2 are working the upper strata—Rodman, Lowville, and Carlim—and quarry No. 3 is opened in the underlying Beekmantown.

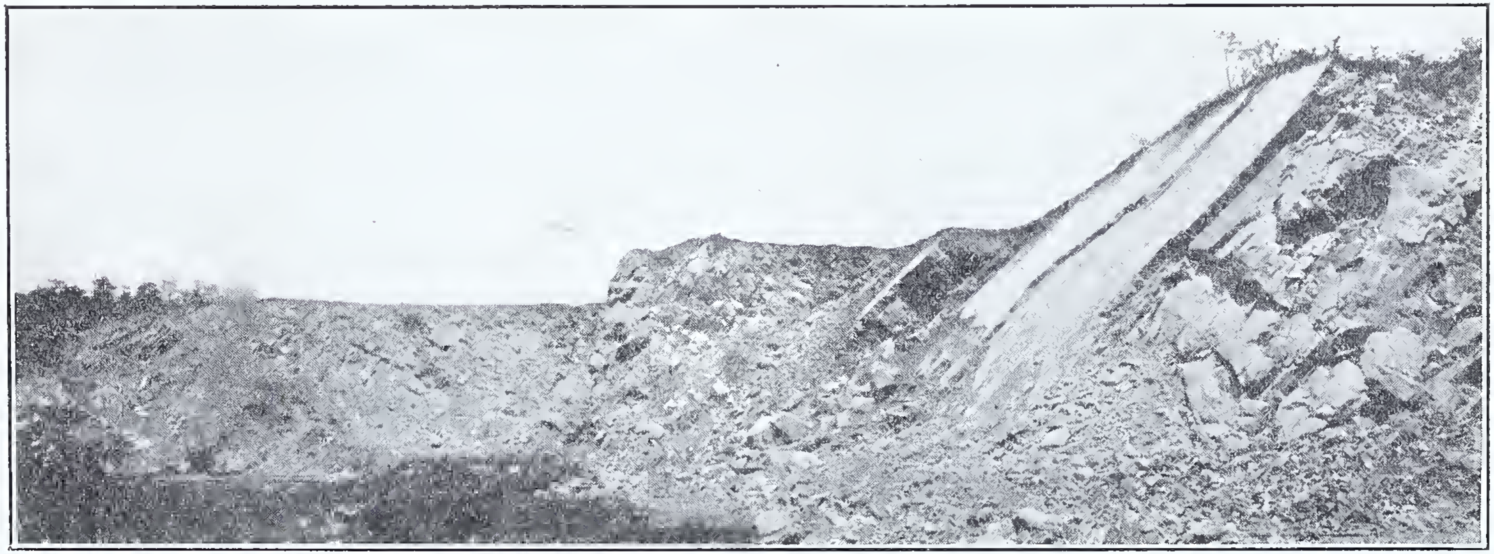
PLATE X.



A. Sheer wall and Carlim limestone, Elk Run quarry.

B. Fault in Carlim limestone, Elk Run quarry.

PLATE XI.



American Lime & Stone quarry, Union Furnace.

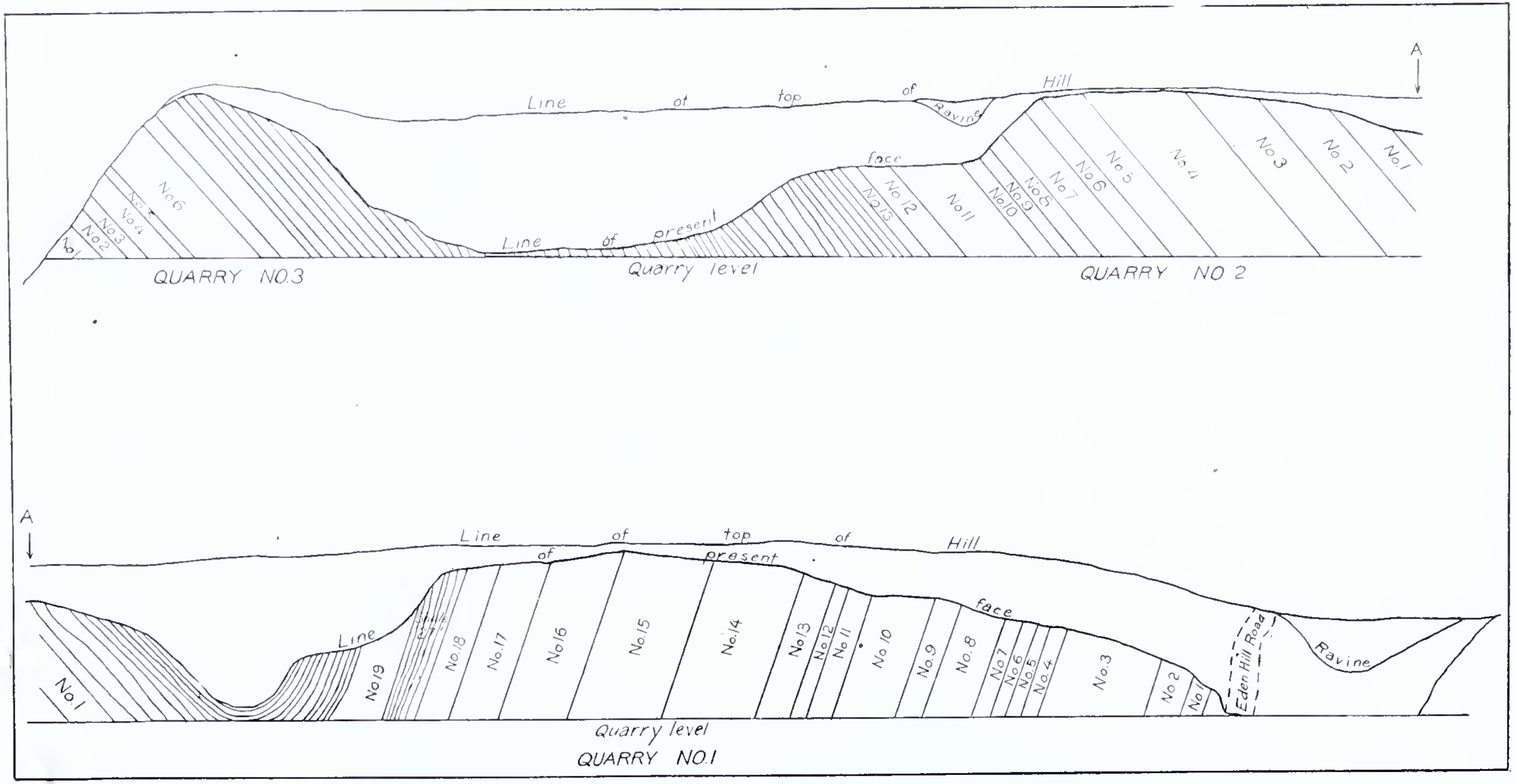


Figure 6. Diagram showing relation of limestone beds and samples for analysis, American Lime & Stone Co. quarries, Union Furnace, Huntingdon County.

Nos. 1 and 2 furnish stone for lime and for flux mainly although some interbedded strata are high in silica and valuable only for concrete or ballast. The stone averages less than 3 per cent SiO_2. The lime made is used for agricultural purposes. The Bellefonte ledge is present in the quarry and, if worked by itself, would yield a chemical lime. The stone from quarry No. 3 is too impure to be satisfactory either for lime or flux and is worked solely for crushed stone.

The large quarries of the American Lime and Stone Company at Schoenberger and Union Furnace, Huntingdon County, were surveyed and sampled under the direction of J. I. Schlegel, general superintendent, in December, 1917, and February, 1919. The dip of the beds in quarry No. 1 is 70° W. and in quarries Nos. 2 and 3, 40-45° E. Quarrying faces range up to 150 feet high. Figure 6 shows the relation of the beds sampled, and the synclinal structure.

The following tables show the thickness and composition of the different beds:

Analyses of Cambro-Ordovician limestone in American Lime & Stone Co. quarry No. 1, Union Furnace, Huntingdon County.

[M. M. Morris, Jr., analyst.]

Sample No.	1	2	3	4	5	6	7	8	9	10
$CaCO_3$	94.23	92.33	90.09	68.83	85.72	78.10	61.72	90.68	90.80	79.75
$MgCO_3$	2.69	1.75	1.41	5.79	3.10	9.38	28.44	4.76	4.76	5.55
SiO_2	2.54	5.16	8.00	24.24	10.48	11.90	8.80	4.06	3.90	13.20
R_2O_3	0.54	0.76	0.50	1.14	0.70	0.62	1.04	0.50	0.54	1.50
Ft. thick	20	28	80	15	12	13	12	42	24	54

Sample No.	11	12	13	14	15	16	17	18	19
$CaCO_3$	81.14	66.30	70.92	93.98	96.14	91.44	90.93	81.28	86.36
$MgCO_3$	4.56	26.20	13.60	2.78	2.40	4.14	2.57	3.68	5.00
SiO_2	13.50	6.80	14.28	3.00	1.26	4.00	5.86	13.72	8.00
R_2O_3	0.80	0.70	1.28	0.24	0.20	0.42	0.64	1.32	0.64
Ft. thick	24	12	30	80	80	60	45	27	40

Analyses of Cambro-Ordovician limestone in American Lime & Stone Co. quarry No. 2, Union Furnace, Huntingdon County.

[M. M. Morris, Jr., analyst.]

Sample No.	1	2	3	4	5	6	7	8	9
$CaCO_3$	91.69	86.74	93.60	90.42	89.66	91.18	64.77	76.45	91.70
$MgCO_3$	2.37	8.38	3.60	2.78	7.82	4.92	10.33	7.81	3.96
SiO_2	5.26	4.36	2.50	6.24	2.20	3.50	23.54	14.20	3.94
R_2O_3	0.68	0.52	0.30	0.56	0.32	0.40	1.36	1.54	0.40
Ft. thick	30	45	50	75	30	20	28	18	10

Sample No.	10	11	12	13
$CaCO_3$	92.45	88.26	77.47	59.05
$MgCO_3$	3.85	7.08	12.99	25.65
SiO_2	3.40	3.50	8.94	14.20
R_2O_3	0.30	1.16	0.60	1.10
Ft. thick	16	24	12	18

Analyses of Cambro-Ordovician limestone in American Lime & Stone Co. quarry No. 3, Schoenberger, Pa.

[M. M. Morris, Jr., analyst.]

Sample No.	1	2	3	4	5	6
$CaCO_3$	51.58	53.21	54.97	54.22	50.32	54.47
$MgCO_3$	42.76	40.43	40.87	40.68	36.38	40.28
SiO_2	4.96	5.80	3.76	4.70	12.70	4.70
R_2O_3	0.70	0.56	0.40	0.40	0.60	0.55
Ft. thick	30	15	15	24	8	50

The same beds outcrop just west of Water Street. Samples were collected here and analyzed. The extreme ranges as shown in the table on a later page probably are explained by some samples being taken from the underlying Beekmantown strata.

Williamsburg.—In the vicinity of Williamsburg a number of large quarries have been opened and are using the upper Ordovician limestones. At Blairfour, the Blair Limestone Co. is quarring limestone beds about 500 feet thick. The strata dip about 45° to the east toward the river. This company has three quarries in the same beds, and their property extends along the strike for about one mile. A 28-foot band of black high-silica rock near the base is suitable only for crushed stone. All the other is sold for flux and averages between 3 and 5 per cent silica.

At Carlim, the Juniata Limestone Co. has a number of openings extending for almost a mile along the west bank of the Frankstown Branch of Juniata River. The structure observed in the various places is extremely complex. Toward the north the beds dip east about 45°, but southward the dip is from 75° to 90° eastward and in several places the dip is north. There has been a large amount of close folding and faulting and there are many calcite veins running through the stone. A number of layers contain too much silica for fluxing stone. The quarries were opened to supply fluxing material for the Cambria Steel Co. and up to 1920 furnished a large quantity of stone with a silica content from 3 to 5 per cent. The poor stone has either been left or was quarried and crushed for ballast and concrete.

About 2 miles southeast of Williamsburg the Pittsburgh Limestone Co. has several quarries along Clover Creek and the Blair Limestone Co. also formerly operated several quarries along the same creek. The operating quarries are mainly along the west side of the creek but at the extreme south end of the property there is a large opening in good stone on the east side of the creek. This one is being worked below the level of Clover Creek with a face almost 200 feet high. In all the quarries the strata dip east toward Tussey Mountain but at different angles. Toward the north the dip averages about 45° but southward some of the beds have dips of 5° to 15°E. There are about 450 feet of quarrying stone between the overlying Trenton and the underlying Bellefonte dolomite, a thickness somewhat greater than Butts gives for the combined thickness of the Rodman, Lowville, and Carlim. All of this is used for flux except about 30 to 40 feet of sandy siliceous to slaty stone that is left in the quarry where practicable. The best stone, the Lowville, lies above the poor stone. The faces of the west quarries are about 160 feet high. The most easily accessible stone of this horizon is rapidly being exhausted.

On the opposite side of the valley at Ganister, 1½ miles northwest of Williamsburg the same strata worked in the east side of the valley have likewise been extensively quarried. On the north side of the river is the St. Clair Limestone Co. quarry, and across the river to the southwest are the Franklin Forge quarry of the Pittsburgh Limestone Co., the quarry of the American Steel and Wire Co., and the quarry of the McKinney Steel Co. All of these are worked for fluxing stone, and all have the same 30 to 40 feet of siliceous rock between the two belts of good stone. The upper band contains the better stone. The beds dip about 60°W. In the Franklin Forge quarry the two bands have been opened separately and a tunnel run through the poor rock to connect the two quarries. At the St. Clair quarry the lower band of fluxing stone has not been opened yet. All of these quarries have passed their zenith.

Southward there is undoubtedly a large amount of good fluxing stone on either side of this valley but up to the present it has not been profitable to open any shipping quarries except in the vicinity of the railroad lines. The local demand is too small to result in much quarrying.

Orbisonia.—In Black Log Valley in the southeast part of Huntingdon County, at the Grove quarry, 1½ miles southeast of Orbisonia, there is some fair fluxing stone that was formerly used in the Orbisonia furnace. The lack of a railroad spur prevents this from being utilized. Analyses are given in the table.

In general one may say that an abundance of good limestone for flux, for agricultural lime and in a few places for chemical lime, outcrops near the margins of the Cambro-Ordovician limestone valleys of Huntingdon and Blair counties, and elsewhere siliceous dolomites that are suitable for crushed stone and for rough building.

Analyses of Cambro-Ordorician limestones of Blair County.

	1a.	1b.	2a.	2b.	3.	4.	5.
$CaCO_3$	90.380	92.115	85.80 to 91.03	90.40	53.870	48.030	94.980
$MgCO_3$	2.245	4.234	3.30 to 5.87	4.06	41.320	37.670	3.860
SiO_2			3.30 to 4.60	4.02			
Al_2O_3			0.40 to 1.88	0.47			
					1.190	2.850	0.254
Fe_2O_3			0.15 to 0.80	0.45			
$FeCO_3$							
Al_2O_3	1.682	.189					
S					.045	.463	0.053
P					.013	.010	0.011
Insoluble	5.880	3.620			2.910	10.380	0.910

	6.	7.	8.	9.
$CaCO_3$	78.186	78.176	91.892	54.571
$MgCO_3$	17.510	10.746	2.875	44.180
SiO_2				
Al_2O_3 Fe_2O_3	1.126	1.850	0.640	0.294
S	0.085	0.149	0.097	0.002
P	0.015	0.029	0.022	0.003
Insoluble	3.210	8.570	4.380	1.330

Analyses of Cambro-Ordorician limestones of Huntingdon County.

	10a.	10b.	11a.	11b.
$CaCO_3$	50.37 to 96.07	78.11	50.82 to 91.21	81.71
$MgCO_3$	1.47 to 39.41	14.51	2.13 to 27.00	11.64
SiO_2	1.00 to 9.70	4.30	1.78 to 16.80	3.88
Al_2O_3 Fe_2O_3	0.58 to 3.46	2.13	0.51 to 3.80	1.39
S	0.02 to 0.27	0.09	0.03 to 0.32	0.115
P	0.004 to 0.024	0.039	0.006 to 0.023	0.010

1. Two limestone quarries near Tyrone. a. Hard and compact; mottled with calcite; light bluish gray. b. Irregularly seamed and mottled with calcite; hard and compact; dark gray; with conchoidal fracture. (Pennsylvania Sec. Geol. Surv., MM. p. 306).

2. Birmingham quarry of Cambria Steel Co. a, Range of many weekly averages. b, Typical weekly average. Analyzed by Cambria Steel Co.

3. Keystone Zinc Co's. limestone. Near Birmingham. Conglomerate-like; irregularly seamed with white crystalline carbonate of lime; color, various shades of gray and bluish gray. (MM p. 307).

4. Borie property limestone. About 6 miles southwest of Birmingham. Wall rock at deep shaft. Hard, compact; minutely crystalline, bluish gray. (MM. p. 307).

5. Mt. Etna Furnace quarry. 5 miles north of Williamsburg. Irregularly seamed with calcite; dark bluish gray, with conchoidal fracture. (MM. p. 306).

6. Springfield Furnace quarry. 5 miles southwest of Williamsburg. Irregularly seamed with thin veins of white crystalline carbonate of lime; generally very hard and tough; dark blue. (MM. p. 306).

7. Rodman Furnace quarry No. 1. South of Roaring Spring. Fine grained; seamed with calcite; brittle; bluish gray. (MM. p. 306).

8. Rodman Furnace quarry No. 2. South of Roaring Spring. Coarse grained; sparkling with calcite; bluish gray, with rough irregular fracture. (MM. p. 306).

9. Rodman Furnace quarry. South of Roaring Spring. On railroad south of Roaring Spring, near Rodman furnace. Fine grained; very hard; pearl gray. (MM. p. 306).

10. Myerly farm just west of Water Street. a. Range of 31 samples; b. Average of 31 samples. Analyzed by Cambria Steel Co.

11. Grove quarry in Black Log Valley, 1½ mile southeast of Orbisonia. Analyzed by Cambria Steel Co.

BEDFORD COUNTY.

The south end of Morrison Cove extends into the northern part of Bedford County about 10 miles. It is about 5 miles wide and is almost continuous with another valley about 16 miles long and 3 miles wide. All of the outcropping Cambro-Ordovician limestones of Bedford County are contained in these two valleys. The geologists of the Second Geological Survey of Pennsylvania found that both of these valleys have two anticlines instead of the normal single one that is observed in most of the limestone valleys of the central part of the State.

Uses.

The limestones of this county are similar to those of Blair and Huntingdon counties but as yet they have been less carefully studied. The principal use for these limestones has been for agricultural lime.

The only quarry in the Cambro-Ordovician limestone in Bedford County seen by the writer is that of the Joseph E. Thropp Iron Company at Ashcom, 2 miles west of Everett on the south bank of Juniata River. This quarry has furnished flux for the iron furnaces at Everett for many years. The limestone is dark blue to black, massive, knotty, and weathers to a bluish gray. Calcite veins are common on the joint planes and slipping along bedding planes is marked. The beds strike N. 35° E. and dip E. 45°. The quarry is 900 feet long, 150 feet wide, and 75 feet deep. It is connected by gravity tram with the crusher on the railroad about 1,000 feet north of the entrance to the quarry. In 1924 the State Highway Department operated the quarry for road metal. A pit has been sunk 45 feet in the floor of the old quarry, and the rock is broken by blasting in 6-inch holes drilled 51 feet deep about 15 feet back of the face. The broken rock is loaded with a Bucyrus shovel in tram cars that leave the pit through a tunnel that connects with the gravity incline. The rock is crushed in an Austin gyratory No. 8 crusher and dry screened to three sizes.

The strata worked seem to include some of the Trenton but mainly the Black River group of limestones. The section exposed in the operating quarry follows:

Section in Joseph E. Thropp quarry, Ashcom.	Feet
Dark blue more or less gnarly limestone	45
Compact blue limestone breaking with a conchoidal glassy fracture, good quality stone	10
Dark blue gnarly rock with shale partings	12
Blue thin-bedded limestones	20
Dark blue gnarly rock, ripple marked	6
Light blue (calico) dense rock, breaks with glassy conchoidal fracture, contains numerous caves in places	30
Dark blue rock, rather highly siliceous	8
Dark blue rock less siliceous than overlying beds	10
Dark blue compact stone, good quality	20
Sandy limestone blotched with limonite on weathered surface	

Analyses of Cambro-Ordorician limestones of Bedford County.

	1	2	3	4	5a	5b	6
$CaCO_3$	69.107	93.014	90.857	85.892	64.75 to 91.65	78.81	51.904
$MgCO_3$	23.951	3.329	3.216	10.637	3.96 to 27.85	15.43	40.022
SiO_2	----------	----------	----------	----------	2.34 to 4.70	3.77	----------
Al_2O_3 }	0.542	0.394	0.360	0.410	0.70 to 2.16	1.48	1.270
Fe_2O_3 }							
S	0.266	0.046	0.103	0.075	0.07 to 0.15	0.10	0.016
P	0.008	0.002	0.006	0.005	0.003 to 0.010	0.0 7	0.024
Insoluble	5.790	3.660	5.130	3.090	----------	----------	6.429

1. Farm of J. Carper, Woodberry Township. (T2 pp. 335-336)
2. Farm of J. Brumbaugh, South Woodberry Township. (T2 pp. 335-336)
3. Farm of M. Kagarise, South Woodberry Township. (T2 pp. 335-336)
4. Farm of D. Dunkle, Snake Spring Township (T2 pp. 335-336)
5. Steel and Koontz property near Ashcom, Snake Spring Township. 7 samples, a. range, b. average. Analyzed by Cambria Steel Co.
6. Farm of D. F. Koons, Colerain Township. (T2 pp. 335-336)

MIFFLIN COUNTY.

The Cambro-Ordovician limestones of Mifflin County are found in Kishacoquillas Valley, a canoe-shaped valley somewhat more than 30 miles long and approximately 3 to 4 miles wide, that extends southwest across the northern part of the county and a few miles into Huntingdon County. At the western end it comes to a point but the eastern portion breaks up into three fingers or prongs known as Havice, Treaster, and New Lancaster valleys. The major part of the valley is drained by Kishacoquillas Creek, which flows east to Reedsville where it turns sharply and flows southward through a gap in Jacks Mountain to join Juniata River at Lewistown. Honey Creek with its tributaries drains the eastern part of the valley and the three subordinate valleys. A considerable part of the valley has no surface streams as the cavernous character of the limestones facilitates drainage by underground channels. A number of small streams running down the sides of the enclosing mountains disappear in limestone sinks. There was formerly a large cave at Naginey that could be entered but the mouth has now been filled.

Geologic structure.

The strata during the Appalachian revolution were thrown into an upward fold (anticline). Erosion has now removed the overlying strata exposing the limestones that form the valley beneath the old anticlinal ridges. On both sides the limestones dip toward the mountains. Shales of the Martinsburg (Hudson River) form the lower slopes of the enclosing mountains with the still younger Oneida and Medina sandstones and conglomerates, because of their greater resistance to erosion, composing the higher mountain ridges. There are a few minor folds and the subordinate valleys at the eastern end owe their existence to the breaking up of the major fold into three smaller anticlines. With such an arrangement the oldest strata are found at the top of the anticline, which is not far from the center of the valley and the upper and younger beds are at the sides. This simple structure is important to recognize for any one who is in search of any particular series of beds.

The limestones of the region have not been mapped as distinct formations as in Centre County, yet there is little doubt but that the same classification could be applied here. The search for low silica stone throughout the valley by the steel companies has shown the presence of the Black River group, particularly the Lowville, and the overlying shaly beds of the Trenton and the underlying dolomitic and more highly siliceous strata. All the work that has been done seems to show that it is useless to look for any of the low silica limestones except near the margins of the limestone where it passes beneath the Ordovician shales.

Quarries.

The limestones of Kishacoquillas Valley have not been extensively utilized. The valley contains few villages; the principal occupation of the people is farming. The prosperous appearance of the region bears witness to the fertility of the soil as well as the thriftiness of the Amish farmers. Formerly a number of quarries were opened to secure stone for agricultural lime but these were all small and intended to furnish lime only for local use. Some of them furnished a small amount of stone for building purposes. When the iron ore deposits of the valley were being mined by the Logan Iron and Steel Co. a quarry was worked for blast furnace flux about 2 miles east of Barr. There were several quarries near Belleville and Allenville.

Naginey.—The Cambria Steel Co. investigated the possibilities of the valley for fluxing stone a few years ago and opened three fine quarries at Naginey that are being extensively operated by the Bethlehem Steel Co. (Plate III B). Nearby the National Limestone Co. has three quarries. These are the only quarry operations of any consequence in the county.

At the Bethlehem Steel Co. quarries five series of workable beds are present. The section with SiO_2 contents is as follows.

Silica in limestone beds at Naginey.

Per cent	Feet
4.50	40
3.60	30
1.10	42
4.50	20
2.50	50

The section is overlain by strata containing more than 8 per cent silica and underlain by other beds in which the silica exceeds 7 per cent. The low silica beds seem to belong to the Lowville and these beds would be valuable for open hearth flux or for the manufacture of high grade lime. All of them are worked together and yield a product averaging about 2.72 per cent SiO_2. An average complete analysis is given on a later page. The strata dip gently toward the shales but variations are to be noted in different parts of quarries.

The good beds will be quarried until the overburden of the high silica stone becomes excessive. It is not possible to work below the level of the nearby creek on account of the cavernous character of the limestone although much good stone is thereby lost.

The National Limestone Co. has operated three large quarries at Naginey, working the same beds as those in the Bethlehem Steel Co's. quarries. From the north quarry some stone has been furnished to the Cambria Steel Co. It averaged about 3½ per cent SiO_2 and some shipments ran as high as 4.33 per cent. At the time of our visit in 1921 the only quarry in operation was the one south of the railroad at Shrader's Station. It was being worked for road metal for the State Highway Department. The beds in this quarry show complex structures with a sharp anticline and small faults. The north quarry exposed regular beds dipping gently to the east.

Some limestones on the Close farm at Siglerville were sampled but there is no quarry here. In 70 samples the silica ranged from 0.44 to 20 per cent, averaging about 4 per cent. Some shaly layers present were high in silica. The magnesia was low in all but a few samples, thus indicating the upper limestone strata.

Reedsville.—On the south side of the Belleville road ½ mile west of Reedsville where there are a few small openings, 23 samples were taken and analyzed for silica. They show a range from 0.80 per cent to 7.48 per cent, averaging 3.69 per cent. The beds were thought to lie below the horizon of the best stone.

At Union Mills good limestone is exposed along Kishacoquillas Creek but conditions are not favorable for quarrying.

One mile east of Belleville on the north side of the road a small quarry exposes about 25 feet of stone of poor quality, containing considerable black flint. South of the road there were also exposures of poor stone dipping about 25° W.

Along Coffee Run about midway of the Kishacoquillas Valley nearly horizontal limestones of rather poor quality are exposed. The lower 34½ feet averaged 3.10 per cent SiO_2, the overlying beds considerably higher.

At Woolen Mills on Coffee Run there are exposures of poor quality limestone. About 1500 feet down stream from the mills some fair stone is exposed. The 17 samples analyzed showed a range of silica of 0.52 per cent to 8.82 per cent, averaging 3.08 per cent. The samples collected represent about 90 feet of beds. Some intervening beds amounting to about 50 feet were concealed. The beds dip 40° S.

The first four analyses that follow are taken from Vol. MM of the Second Geological Survey of Pennsylvania and the exact location of the quarries is uncertain.

Analyses of Cambro-Ordovician limestones of Mifflin County

	1	2	3	4	5a	5b	6
$CaCO_3$	97.651	81.178	70.214	54.285	43.30 to 77.17	55.87	92.46
$MgCO_3$	1.131	13.498	24.415	36.109	17.55 to 40.96	31.71	3.85
SiO_2					3.33 to 9.24	6.22	2.72
Al_2O_3	0.426	1.253	1.360	1.422	1.02 to 3.92	2.02	0.88
Fe_2O_3							
S	0.034	0.054	0.034	0.151	0.04 to 0.13	0.07	1.03
P	0.039	0.025	0.016	0.011	0.007 to 0.018	0.11	0.13
Insoluble	0.760	4.530	4.050	8.010			

1. Douglas Campbell quarry, two miles from Belleville. Fossiliferous limestone from top of II. Specimen sparkles with calcite; Slightly coated with iron oxide, light bluish gray, with rough fracture. (MM. p. 308)

2. Andrew Campbell quarry. Mottled black and gray limestone with drusy cavities. (MM. p. 308)

3. Andrew Campbell quarry. Light bluish gray limestone; rather hard and tough. (MM. p. 308)

4. Greenwood Ore Bank limestone. One mile from Belleville. "Magnesian limestone." Hard and tough; sparkles with calcite; dark bluish gray. (MM. p. 308)

5. Taylor Farm upper end of Reedsville. a. Range of 16 samples. b. Average of 16 samples. These samples seem to represent strata below the Lowville. Analyzed by H. A. Hosmer.

6. Naginey quarries of the Bethlehem Steel Co. Analyzed by Cambria Steel Co.

FULTON COUNTY.*

The only limestones of Cambro-Ordovician age in Fulton County are confined to McConnells Cove, an anticlinal valley of the eastern part of the county. The limestone area is about 3 miles wide in the widest portion, narrowing both to the north and the south. It extends 8 miles north and 10 miles south of McConnellsburg.

As no railroad enters the county the limestones have been worked solely for local use. They have been quarried for lime for agricultural purposes mainly but limited quantities have been used for flux and for building purposes and in recent years for highways and for concrete.

The largest quarry in the county is on the Patterson Brothers farm half a mile south of McConnellsburg along the bank of Big Cove Creek. The beds strike N. 20° E. and dip W. 20°. Most of the limestone is dark blue, weathering light gray, but the quarry face, which is 70 feet high, contains two bands 5 and 3 feet thick of yellow, platy, drusy limestone. This material is discarded, only the good blue rock being used. The quarry is operated by the State Highway Department as a source of road metal. The rock is crushed at the quarry and delivered by automobile trucks. After operating for 5 years, a quarry face 300 feet long has been developed. About 30 men are employed.

C. J. Brewer opened a small quarry 2 miles south of McConnelsburg about 1917. It is well located for development and requires no stripping. The following analyses are from samples taken by him in 1917 and 1922.

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*By R. W. Stone.

Analyses of Cambro-Ordorician limestone from McConnellsburg.

[Pennsylvania Bureau of Chemistry, analyst]

No.	D-51	D-53	D-249	D-250
Calcium oxide	36.45	30.20	48.11	27.72
Calcium carbonate	65.01	53.88	85.82	49.47
Magnesium oxide	8.95	17.49	4.95	17.91
Magnesium carbonate	18.72	37.57	10.35	37.46
Insoluble matter	12.65	4.66	3.10	11.30

A quarry in this limestone on the Walter Gress farm 2 miles southeast of McConnellsburg has a face about 60 feet long and 30 feet high but it has not been worked in many years. C. H. Stenger quarries limestone on the Geo. Magsam farm in the same vicinity from a face 40 feet long and 12 feet high. The stone is burned in an open heap and used for both building and agricultural lime.

The following analyses are from the Second Geological Survey of Pennsylvania.

Analyses of Cambro-Ordorician limestones of Fulton County.

	1	2
$CaCO_3$	76.964	51.143
$MgCO_3$	19.327	39.301
SiO_2	2.820	9.040
Al_2O_3	0.840	0.660
Fe_2O_3		
S	0.140	0.207
P	0.005	0.003

1. Farm of John Sowers, Ayr Township. 2. Greathead quarry, McConnellsburg. Analyses by A. S. McCreath, (Pennsylvania Sec. Geol. Surv., T2, p. 336)

CHAPTER V

HELDERBERG AND TONOLOWAY LIMESTONES.

In the physiographic province known as the "Appalachian Valley" that extends across central Pennsylvania in a broad sweeping curve from New Jersey to Maryland, among the persistent rock strata are those grouped under the name of "Formation No. VI" or the "Lower Helderberg limestones" by the earlier geological surveys. Although not a unit, as can be seen by the correlation table that follows, the series is largely responsible for the numerous narrow steep-sided valleys that are such a prominent feature in the central part of the State. Underlain and overlain by argillaceous and siliceous strata, these calcareous beds are valley formers because of their soluble character in contrast to the less soluble shales and sandstones.

The Helderberg limestones occur where the strata have been thrown into great longitudinal folds which subsequently have been worn down by erosion. This brings the limestones to the surface as outcropping beds in numerous places. The map showing the surface distribution of the limestones exhibits their repetition and their weaving back and forth throughout the area. This feature is especially prominent in the south central part of the State.

The Helderberg limestones outcrop in the following counties: Monroe, Carbon, Schuylkill, Lebanon, Perry, Juniata, Mifflin, Snyder, Union, Northumberland, Montour, Columbia, Lycoming, Clinton, Centre, Huntingdon, Blair, Bedford, and Fulton.

The classification and correlation of the Helderberg limestones has long been a subject of dispute which even yet is not ended. One of the most recent studies on the subject based primarily on the paleontological characteristics, which undoubtedly are of the greatest value, is by John B. Reeside, Jr.[32] He collected specimens and carefully studied several sections in Central Pennsylvania. His conclusions are accepted by the writer and various portions of his report will be quoted in the following pages. Notwithstanding the acceptance, in the economic descriptions the Tonoloway is considered as a part of the Helderberg series. The following table is adopted from this report:

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[32] Reeside, J. B. Jr., The Helderberg limestone of central Pennsylvania: U. S. Geol. Survey Prof. Paper 108, pp. 185-225, 1918.

Correlation of the Helderberg limestone and adjacent strata.

	White, Montour County Grovania, *	White, Snyder County Selinsgrove,†	White, Northumberland County Dalmatia,†	Claypole, Perry County Clark's Mill‡	D'Invilliers, Mifflin County Lewistown‖	White,‖ Huntingdon County Mapleton¶	Platt, Blair County Tyrone§	White, Monroe County**	Reeside††
DEVONIAN	**Oriskany sandstone**	Oriskany sandstone	Oriskany sandstone	Oriskany sandstone	Oriskany sandstone	Oriskany sandstone	Oriskany sandstone	Oriskany sandstone	Oriskany shales and sandstone
	Stormville shales	**Stormville** shales	Stormville shales	Flint shales	Lewistown limestone Lime shale	Stormville shale	Lewistown limestone	Stormville shales	
						Lewistown limestone Lime shale		Stormville conglomerate	Helderberg **New Scotland limestone**
					Lower massive limestone			Stormville limestone	
	Stormville conglomerate	Stormville and Bastard limestones	Stormville and Bastard limestones			Massive limestone		Decker Ferry limestone	**Coeymans** limestone
				Clarks Mill shales				Decker Ferry sandstone	
	Stormville and Bastard limestone							Decker Ferry shale	Keyser limestone
SILURIAN	Bossardville limestone	Bossardville **limestone**	Bossardville limestone	Lewistown limestone		Shaly limestone		Bossardville limestone	Tonoloway limestone
								Poxono Island shales	
								Poxono Island limestone	

*Pennsylvania Second Geol. Survey Rept. G7, p. 88, 1883.
†Idem, p. 92,93.
‡Idem, Rept. F2, p. 182, 1885.
‖Idem, Rept. F3, p. 256, 1891.
¶Idem, Rept. T3, 1885.
§Idem, Rept. T, 1881.
**Idem, Rept. G6.
††U. S. G. S. Prof. Paper No. 108, p. 186.

As the field investigations to secure data for this report did not permit sufficiently detailed study to establish the divisions of the series through the State, the lithologic descriptions of the various formations given by Reeside are quoted.

TONOLOWAY LIMESTONE.

"The type exposures of the Tonoloway limestone are in the lower slopes of Tonoloway Ridge, and the type locality is just west of Rock Ford, W. Va., where Great Cacapon River cuts through the ridge. Typically it is composed of finely laminated light-gray lime stone and calcareous shale and is generally more shaly toward the top.

"The Tonoloway formation in central Pennsylvania has, at all the exposures studied except Tyrone, the same characteristic lithology, consisting of platy, in places laminated fine-grained gray limestones and calcareous shales. The uppermost beds in the Susquehanna region are heavy, pure, and very dark. At Tyrone the strata referred to the Tonoloway are relatively light cream-colored to buff limestones, in places platy and in places containing shale. These beds probably represent a special facies very much like the Wills Creek shale of Maryland. Indeed, if there were sufficient evidence of an unconformity and hiatus at the top, the lithology of these beds would suggest their correlation with the Wills Creek. The Tonoloway at Tyrone also contains a bed of material that seems to be siliceous oölite.

"The Tonoloway is not fully exposed at any of the localities studied. The maximum thickness observed is 325 feet.

"The Tonoloway and Keyser succession has been considered by most observers as uninterrupted, but Ulrich believes the two limestones to be separated by a marked break. The change from the platy fissile gray limestone of the Tonoloway to the much thicker-bedded nodular bluish limestone of the Keyser, in some places very dark in color, is usually sharp. Even where the uppermost Tonoloway is massive, the nodular structure of the Keyser permits a separation."

HELDERBERG LIMESTONE.

General character.

"The Helderberg formation is a series of calcareous deposits of varied character. It includes some shale but is chiefly limestone. In lithology individual beds may represent any stage in the gradation between a coarse agglomeration of fossil fragments and a dense, very fine grained subcrystalline rock, or between a somewhat calcareous shale and a laminated impure limestone. Some parts of the formation have in all exposures much bedded chert, and locally chert is present as nodules in other parts of the formation. In very minor quantity arenaceous limestone and even calcareous sandstone are present.

"Four members are recognized in the Helderberg limestone—the Keyser limestone at the base, and above it, in order, the Coeymans limestone, the New Scotland limestone, and the Becraft limestone."

Keyser limestone member.

"The Keyser limestone forms the larger part of the Helderberg of central Pennsylvania. It is divisible into two major lithologic units—a lower limestone series with many nodular layers and an upper series of relatively shaly limestone, which contains very few nodular beds. At Tyrone no nodular limestone whatever was recognized, but everywhere else it is a prominent feature. At Mapleton and near Lewistown a thick bed of very pure massive crinoidal limestone lies near the base of the member. Here and there the Keyser contains chert and in many places Stromatopora-bearing beds.

"The thickness is variable in the area studied, ranging from 88 feet in one of the Tyrone sections to 202 feet at Selinsgrove Junction."

Coeymans limestone member.

"The Coeymans member is variable in its lithology. In the west it is locally arenaceous at the base and consists of coarse crinoidal limestone in the upper part. Farther east this sandy character extends through the whole of the member and becomes so pronounced at Grovania that the Coeymans is a sandstone. Usually chert is present.

"The thickness of the Coeymans in the sections studied varies from 3 to 10 feet, though it is possible that the minimum thickness should be increased by including some of the overlying limestone."

"The Coeymans-Keyser boundary is everywhere strikingly clean cut. The uppermost beds of the Keyser are platy, banded impure limestones. The base of the Coeymans is coarse, commonly arenaceous limestone or sandstone. The faunal change is likewise sharp."

New Scotland limestone member.

"The New Scotland member usually has a thin bed of limestone at its base, above which lie shales, interbedded in many places with impure limestone and with white chert.

"In the vicinity of Dalmatia the basal limestone is very thin or lacking. It was likewise not observed in Perry County. At Tyrone it is 12 feet thick; at Lewistown, 6 feet; at Selinsgrove Junction, 12 feet; at Grovania it seems to be about 13 feet thick and contains much shale. The limestone is arenaceous at Selinsgrove Junction, but in most other places it is simply a coarse-grained bluish-gray fossiliferous rock."

"The shale is ashy gray, fissile or splintery, and fine grained and contains more or less impure limestone in thin layers. It weathers yellow and is not usually very fossiliferous. The only measurement of the thickness, made at Selinsgrove Junction, gives a total of 44 feet. Some uncertainty as to the position of the upper boundary renders the accuracy of this figure only approximate."

"The New Scotland-Coeymans boundary is not well defined lithologically."

Becraft limestone member.

"No lithologic or faunal evidence of the presence of the Becraft member of the Helderberg was obtained at any locality studied."

Uses.

The Helderberg (including Tonoloway) limestones have been quarried in hundreds of places throughout the counties where they outcrop. The main use has been for the manufacture of agricultural lime, building lime, for flux, and for road metal and concrete. In a few places high grade chemical lime has been made.

Most of the descriptions by counties that follow are by Mr. Lloyd W. Fisher who did the major portion of the field work in the Helderberg areas.

MONROE COUNTY.

The Helderberg series extends in a narrow band entirely across the southern part of Monroe County. They appear at Decker's Ferry and continue to the southwest, close to Delaware River to Delaware Water Gap and thence in a small valley parallel and a short distance north of Blue Mountain to the Carbon County line.

Throughout the area designated these limestones have not been recognized by continuous outcrops on account of the heavy cover of glacial debris and talus derived from the Oriskany sandstone ridge along the south side of which the Helderberg outcrops and beneath which it disappears as the strata almost uniformly dip northward.

I. C. White in his report on Monroe County[33] has given an excellent description of the Helderberg series from which the following extracts are taken as the writer did not have opportunity to do much field work in this region. White recognized the divisions given on a previous page in the table of formations. He gives the following generalized section along the Delaware and Lehigh rivers.

Generalized section on the Delaware River.

		Feet.
1.	Oriskany sandstone, consisting of alternating beds of quartz conglomerate, and calcareous chert	50
	Lower Helderberg.	
2.	Stormville calcareous shales, ashy, or dark gray, fossiliferous, sometimes cherty and containing limestone at base	160
3.	Stormville conglomerate, alternating beds of quartz conglomerate, and siliceous pebbly limestone	25
4.	Stormville limestone, cherty, sandy, massive beds, containing numerous fossils, *Pentameras galeatus*, *Stromatopora*, *Favosites*, and *Receptaculites* being especially numerous	75

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[33] Pennsylvania Second Geol. Survey Report G6.

5.	Hydraulic cement bed ("Peth stone" of Cook)	5
6.	Decker's Ferry limestone, bluish, shaly, containing vast numbers of *Leperditia alta*, at top	20
7.	Decker's Ferry sandstone, a very hard, pebbly, often calcareous sandstone, filled with fossil shells, *Aviculas*, *Chonetes*, and others	15
8.	Decker's Ferry greenish shales, sometimes calcareo-siliceous	15
9.	Bossardville limestone, divisible into two well marked subdivisions, (a) of 65′ and (b) of 25′; the upper (a) almost non-fossiliferous, dark blue, or almost black, splitting into slate-like, thin, layers; the lowest, (b) dark-gray, always presenting a banded or striped appearance, and often exhibiting a true columnar structure (Stylolites); thickness of both a and b	90
10.	Poxono Island shales, buff, calcareous and magnesian	200
11.	Poxono Island limestone, bluish-gray, very compact, fossiliferous, extending down to the bottom of the Lower Helderberg on top of the Clinton red beds	5
	Total of Lower Helderberg	610

White believed that the (lower) Helderberg thinned out to the westward being replaced by the deposition of sediments that form a part of the Oriskany formation.

Of the series as given above, the only strata possessing much economic value is the Bossardville limestone, that is probably to be correlated with the Tonoloway limestone of Silurian age and by the recent classifications is not a part of the Helderberg series. For the present purpose, however, it is described as part of the Helderberg.

"All the great limestone quarries of Monroe are in this rock, and it furnishes practically all the lime burned in the county.

"Its top comes out of the Delaware river just above Decker's Ferry and it is quarried at the roadside on the bluff of the river west of the Ferry.

"The thickness of the interval varies from 75′-100′ and is divisible into two portions, an upper and a lower, which are very unlike in aspect and composition. The upper or quarry portion is usually about 65′ thick and has a prevailing dark color, sometimes almost black, the extreme upper portion excepted, which is generally gray or bluish-gray; through the dark portion especially radiate seams of calcite; the rock breaks with a very sharp angular fracture and has a thin flag-like bedding, and is entirely non-fossiliferous, if we except minute dark specks which may be *Beyrichia*.

"This quarry portion of the Bossardville limestone is the only limestone bed of No. VI which extends through from this district to the Lehigh River. The Bossardville limestone has a thickness of 30′-40′ where it crosses the Central R. R. of New Jersey, one mile below Bowman's station. It possesses the same physical characters there that distinguish it in Monroe.

"Samples of the Bossardville quarry limestone were collected at several localities, and analyzed in Mr. McCreath's laboratory at Harrisburg:

Analyses of Bossardville limestone.

	I	II	III	IV	V	VI	VII	VIII
Carbonate of lime	94.285	87.928	82.732	93.267	93.875	88.821	94.285	92.196
Carbonate of magnesia	1.528	1.937	2.830	1.384	1.309	2.345	2.118	2.171
Oxide of iron and alumina	0.700	2.110	1.360	0.840	0.680	0.710	0.540	1.100
Sulphur	0.056	0.229	*.695	0.113	0.153	0.207	0.207	0.154
Phosphorus	0.014	0.019	0.007	0.010	0.010	0.013	0.015	0.020
Insoluble residue	2.850	7.860	11.930	4.250	3.920	7.650	3.020	4.260

"I, II. From Bossardville quarries, Hamilton township, Monroe county.
"III, IV, V, VI, from C. Van Auken's quarry, Middle Smithfield township, Monroe county.
"VII, VIII, From J. H. Brown's quarry, Smithfield township, Monroe county.

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*Average of two determinations.

"The limestone from this horizon burns readily into a light gray lime, much valued for agricultural and building purposes, though it is seldom white enough to be used for plastering. At Bossardville and vicinity, several hundred thousand bushels are annually burned and hauled far and wide into the surrounding country.

"The opinion prevails among the farmers that this limestone is occasionally absent for long distances, coming in again suddenly; thus for instance, no quarry of it has been opened between that near Experiment Mills, on Brodhead, and one mile west of Stormville in Hamilton township, a distance of nearly five miles; hence the farmers along this line believe it absent. The truth is that there are no natural exposures here because the limestone is buried by drift and surface debris, shed from the steep slope of Walpack (Godfrey's) ridge, since its line of outcrop would nearly always be found down along the northern margin of Cherry valley. Hence this valuable limestone is very probably present on every farm, but covered up. The farmers owning land along the northern margin of Cherry valley, should do some judicious digging in order to test the matter.

"In passing south-westward from Bossardville, this limestone's outcrop is again covered up by the vast heaps of Oriskany debris, and is not seen again until we pass west from Saylorsburg into Ross township. There in the vicinity of Samuel Lessig's, the Bossardville limestone has been quite extensively quarried, though it is not so thick as usual nor so pure, and has been so much crumpled and folded as to have slaty cleavage and aspect, being in fact partially metamorphosed.

"From the vicinity of Lessig's, this limestone is not seen again until we come to the neighborhood of Kunkletown, in Eldred township, its outcrop being constantly concealed under the surface debris, principally of Oriskany sandstone. West from Kunkletown, however; the great Oriskany beds are disintegrated, and the limestone then comes out to the surface, where it is quarried, and burned quite extensively. It is much twisted and contorted, however, so that it is difficult to decide which way the dip is going. It is of course possible that the limestone may be entirely absent in the intermediate spaces where it makes no appearance on the surface, but the probabilities are that it is present, concealed under the great heap of debris.

"The lowest 25′ of the Bossardville limestone is very different in aspect from that portion usually quarried for lime, having a dark-gray color, and a peculiar banded appearance made by fine lines of lamination of different colors, gray, whitish, blue etc. It also often possesses a genuine columnar structure which is finely shown at the Experiment Mill's quarry, above the Delaware Water Gap, where the rock exhibits a prismatic structure, like basaltic columns. This structure does not exist all through the 25′, but is confined to certain layers, the one exhibiting it most decidedly coming 7′ above the base of the stratum and having a thickness of 3′. The columns or stylolites are inclined to the south-east at an angle of 75°, while the dip of the rocks is only 35° in the same direction; thus it is probable that the structure in question has originated through the action of the forces that produce cleavage, because the rocks which exhibit it show no traces of overheating.

"The same structure is seen just below the falls at Shawnee in Smithfield township, though the limestone exhibiting it there comes higher in the series than the one at the base of the Bossardville beds. This stratum, in physical appearance, answers perfectly to the description of Prof. Cook's Ribbon limestone which is found at the base of the series in New Jersey; although many of the layers in the Stormville limestone often possess the ribboned aspect.

"A specimen of the columnar limestone, from the Experiment Mill's quarry, had the following composition, as analyzed by Mr. McCreath:

Carbonate of lime,	73.428
Carbonate of magnesia,	2.648
Oxide of iron and alumina,	2.970
Insoluble residue,	20.240

"From this analysis, one might infer that it would make a pretty fair hydraulic cement, and I was informed that the limestone was tested for that purpose on one occasion at Bossardville, where it shows under the quarry limestone. It is reported as having made a very good hydraulic cement.

Stormville hydraulic cement bed.

"Immediately below the Stormville limestone just described, there occurs a bed of water lime which seems to be quite persistent from the extreme eastern line of the district southwestward beyond the center of Monroe county, or at least as far as Stormville, from which locality the stratum in question was designated. It is seldom over 5′ thick though occasionally attaining to 10 feet. The rock is usually of a pale-buff color, and breaks with the peculiar earthy fracture characteristic of hydraulic limestones; non-fossiliferous, although just under it millions of *Leperditia alta* are found.

"This bed is seen in the steep slope of the hill facing the Delaware River near Decker's Ferry, at the eastern line of Monroe, and at numerous localities from there on, southwestward to Stormville.

"The following analysis of specimens from several localities in Monroe show the composition of the Stormville cement bed as determined by Messrs. McCreath and Stinson:

I. Near Decker's Ferry, Middle Smithfield, Monroe County.
II. Same locality, Middle Smithfield Tp., Monroe County.
III. Land of J. DeWitt, Middle Smithfield Tp., Monroe County.
IV. Land of J. DeWitt, Middle Smithfield Tp., Monroe County.
V. Stormville, Hamilton Tp., Monroe County.

	I	II	III	IV	V
Carbonate of lime	38.910	36.428	37.714	37.107	43.839
Carbonate of magnesia	23.724	17.481	25.351	26.410	29.664
Oxide of iron	3.357	3.285	6.290	3.357	2.607
Alumina	4.163	7.735		3.673	3.653
Sulphur	.065	----------	.113	----------	----------
Phosphorus	.038	----------	.027	----------	----------
Insoluble residue	27.420	28.720	29.690	28.460	17.560

"The insoluble residue in each of the above after ignition gave the following:

	I	II	III	IV	V
Silica	24.150	23.940	24.850	23.970	13.630
Oxide of iron and alumina	2.500	2.740	2.450	2.740	2.040
Lime	0.220	0.110	0.260	0.090	0.120
Magnesia	0.404	0.183	0.490	0.227	0.144
Totals	27.274	26.973	28.050	27.027	15.934

"No attempt has ever been made to manufacture hydraulic cement from this bed so far as I could learn; but it would seem from the composition given above that portions of this stone might be selected which would make a very fair cement. At the locality where specimens III and IV were obtained the bed is 10′ thick, so that some of it would almost certainly make hydraulic cement."[34]

The Helderberg quarries are still in operation. When visited by the writer a few years ago two quarries were being worked for agricultural lime for local use. One operated by Charles H. Heney produces about 10,000 bushels of lime annually. The stone is blue with numerous thin bands (ribbon structure) and is said to contain from 85 to 90 per cent calcium carbonate.

CARBON, SCHUYLKILL, AND LEBANON COUNTIES.

The Helderberg limestones are not well developed nor of much economic value in Carbon, Schuylkill and Lebanon counties. They gradually thin and seem to disappear near the Swatara Water Gap and have not been recognized in Dauphin County.

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[34] Pennsylvania Second Geol. Survey Rept. G6, pp. 136-137, 141-145, 1882.

Just north of the Lehigh Gap in Carbon County White[35] has given the following section:

	Generalized section on the Lehigh River.	Feet
1.	Oriskany sandstone, a coarse, massive, reddish-gray, quartz conglomerate, nearly destitute of fossils	200
2.	Cherty, calcareous sandstone containing casts of fossils	10
3.	Oriskany shales, containing some cherty layers together with a few thin beds of sandstone	60
4.	Concealed	20
5.	Oriskany shales. with thin layers of reddish sandstone	50
6.	Decker's Ferry greenish shales, and calcareous sandstone	30
7.	Bossardville limestone, blackish, slaty fracture, filled with streaks of calcite	40
8.	Poxono Island shales, buff, gray, and greenish, calcareous, variegated with red near the base	225
	Total of Lower Helderberg, ...	295

These limestones were formerly quarried near the Lehigh Gap and were used in the manufacture of hydraulic cement.

Although exposures are almost entirely lacking, due to their concealment by much debris, the Helderberg limestones are believed to extend continuously to Schuylkill Haven on the Schuylkill River. There due to sharp folding, the strata make an eastward loop, cross the river at Auburn and continue westward. In the Swatara Gap section a few beds of limestone are exposed.

PERRY COUNTY.

The Helderberg limestone enters Perry County in the northern part, northeast of the Juniata River. It is exposed on both flanks of a broad anticline which forms Pfoutz Valley. Turning back about four miles from the Susquehanna the outcrop assumes a southwesterly trend, and, due to plications and rolls, has a width of two miles in Raccoon Valley. To the southwest in the Blain area there are numerous folds and rolls, which are best seen in the McVey quarry.

Between Andersonburg and Center the outcrop of the formation widens to five miles in Sherman Valley. North of Bloomfield, the county seat, it crosses the county in two distinct bands, one along Buffalo Hills and the other on the north and south sides of Stony Ridge.

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[35] Op. cit., p. 129.

At Iroquois station on the Pennsylvania Railroad, it is offset across the Juniata River by a continuation of the Perry County fault. The plane of the fault could not be traced.

The limestone band runs southwesterly to Elliotsburg and is well developed in Tyrone township due to numerous rolls and folds. Then, bending slightly to the north of east to a point south of Bloomfield, it runs sharply off to the southwest to Oakgrove.

Several small areas of the limestone are exposed as outliers on the west side of the Juniata River.

Bloomfield area.

Because of the great amount of folding, the Lewistown limestone of White covers a great deal of territory to the north of Bloomfield. The ridge is formed by the outcrop and is known locally as Limestone Ridge. It includes the excellent Clarks Mill exposure cited by Reeside and visited by the writer.

In the Harmon quarry, three quarters of a mile north of the Court House, the following section is exposed:

Section of Helderberg limestone near New Bloomfield.

	Feet
Steel, gray rather shaly limestone	10
Blue massive limestone, weathers yellow	15
More or less crumbly limestone	5
Vein of calcite 2 inches	
Bluish limestone sandy and clayey	2
Hard, siliceous limestone	2
Gray to blue limestone beds two feet thick	11

The quarry is no longer in operation; two kilns in ruins show signs of former activity.

One of the type localities of the Helderberg is about one and one-quarter miles northwest of the town along the abandoned Newport & Sherman's Valley Railroad. It is one of the best exposures in the central portion of the State. Although the fossils are abundant they are not very well preserved and hence are very difficult to identify.

According to Reeside,[36] the upper 140 feet comprise the Keyser formation and are apparently the same as those named by Claypole as the Clark's shales.

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[36] U. S. Geol. Survey Prof. Paper 108, p. 215-216, 1918.

Section at Clarks Mill, about 2 miles northwest of New Bloomfield.

	Thickness in feet.
Concealed by residual clay, filled with white blocky chert, fragments of coarse sandstone, and thin, platy, shaly limestone. Immediately above the top of the Keyser, weathered Gypidula valves and segments of a large crinoid column are abundant and indicate the probable presence of the Coeymans member of the Helderberg.	
Helderberg limestone (Keyser limestone member):	
Limestone, fissile, platy, dark gray; fragments ring when dropped; no chert; fresh surface shows distinct lamination	2.0
Limestone, thin bedded, dark gray, with much interbedded black chert; one layer is about 10 inches thick, compact, bluish gray, with conchoidal fracture	5.8
Limestone, thin bedded, full of crinoid fragments and other fossils, crystalline	1.0
Concealed by talus	2.7
Limestone, thin bedded (1 to 3 inches), a little nodular, bluish gray; some of the layers are compact, with conchoidal fracture; others are subcrystalline, crinoidal, and crammed with fossils; the unit, however, looks homogeneous	20.1
Limestone, thin bedded, blue crinoidal; subcrystalline, and crammed with fossil fragments	1.5
Concealed	3.0
Limestone, crinoidal, bluish	.5
Concealed	4.7
Limestone, gray, crammed with ramose bryozoan	1.0
Concealed	2.0
Limestone, compact, hard bluish	.5
Concealed	27.6
Limestone, thin bedded, dense, bluish, conchoidal fracture	4.0
Concealed	20.0
Limestone, thin bedded, blue, nodular	5.0
Concealed	4.6
Limestone, very thin bedded, nodular, dark gray	4.2
Concealed	3.0
Limestone, thin bedded, much weathered and stained, debris full of fossils	6.0
Limestone, thin bedded, rather nodular, dark gray; upper 3 feet heavier bedded	9.9
Concealed	3.0
Limestone, thin bedded, very nodular, bluish gray	6.6
Limestone, single heavy bed, compact, dark gray	1.0
	139.7
Tonoloway limestone:	
Limestone, rather massive, dark gray, not nodular	3.0
Limestone, fissile, platy, yellowish, banded; fossils very rare, very different from overlying beds; gives a shingle-like talus; dark gray on fresh fracture	5.9
Limestone, single bed, dark gray	1.0

Tonoloway limestone—Continued.	Thickness in feet.
Limestone, dark gray, separated into 1-inch courses by silicified seams 1/8 inch thick, which stand out a little in relief	2.6
Limestone, single bed, knotty, dark gray; weathers into laminae	3.6
Limestone, platy, shaly; weathers into plates	4.0
Shale, contorted, yellow, partly concealed	4.0
Limestone, knotty, irregular, yet massive	5.0
Concealed	7.5
Limestone very thin bedded, platy, dark gray	8.6
Limestone, massive bed, dark gray, breaks into thin plates	6.2
Concealed	4.5
Limestone, massive, dark gray, breaks into thin plates	6.0
	61.9

The fossils found in the Clarks Mill area include many forms. Reeside has identified 45 species from this locality.

Pfoutz Valley area.

This area lies in Liverpool township and when visited contained no working quarries. The State Highway Department operated a quarry at the head of the valley in Liverpool Township in order to secure stone for the construction of the State highway from Millerstown to Liverpool.

Section exposed in quarry in Liverpool Township.

	Feet
Overburden	6
Shattered limestone, no bedding visible	9
Bluish to black massive limestone	8
Thin yellowish shale 2 inches	
Homogeneous limestone, beds one to ten inches	10
Thin-bedded, bluish limestone with fossils	12
Numerous veins of calcite with fluorite at base	....

The quarry is about 200 feet long and there is much evidence of cave formation to the east, and much shattering to the west where the rocks pitch steeply into the hill.

Northwest of the quarry the rocks form the northern flank of the anticlinal valley and pitch under Turkey Ridge. Here are located the abandoned quarries of Messrs. Parner, Rumbaugh and Kaufman. Mr. Parner stated that owing to the ease with which lime could be secured from the Dalmatia area, the quarries in this district have never been extensively worked. The Parner quarries showed considerable calcite vein material in the lower beds.

The upper limit of the Helderberg along the southern border of the valley may be mapped because of an outcrop of chert along the northern flank of Wildcat Ridge.

Generalized section of the Helderberg limestones of Pfoutz Valley.

	Feet.
Blue to blackish limestone, massive	2.0
Yellowish shaly materials	6.5
Fossiliferous, massive, blue limestone	12.0
Thin-bedded bluish limestone	15.0
Dark blue limestone with veins of calcite, and some fluorite forming the base of the quarries	20.0

Blain area.

In the Blain area located along the narrow gauge railroad of Sherman Valley, about one and one-half miles north of the station, the rolls and plications of the Helderberg are well exposed. The best exposure occurs in the quarry of Samuel McVey where there is a double syncline with beds pitching to the north and maintaining an almost due east-west strike. Along the southern outcrop there has been much shattering and the beds are more or less shaly and are scantily fossiliferous. 100 feet down, the dip suddenly reverses and synclinal conditions are presented.

The basal beds are very dark and show few fossils. They seem to belong to the Tonoloway. The beds are about two feet thick, but where the harder and bluer beds occur they are nearly three feet. The blue limestone is in turn overlain by a harder limestone which is 18 inches thick. Above this is about 20 inches of a harder, shelly blue limestone. Above it is a 3-foot bed of chocolate-colored limestone. This is the main quarry rock of the lower bench of this triple-benched quarry.

The second bench which is about 10 feet high overlies a shaly bed which is occasionally worked. In the third bench which showed a second anticline, there is about 15 feet of shaly limestone which supplies the draw kilns. The axis of the anticline is exposed. The length of the quarry is 200 feet.

The outcrop may be traced across the hill for a distance of half a mile where the rock is again exposed in the abandoned McVey quarry.

Section exposed in the McVey quarry.

	Feet.
Keyser limestone:	
Upper, shaly and platy limestone	15
Bluish limestone, weathers yellow	10
Slaty ledge, with fossils poorly preserved	1
Hard, siliceous blue limestone	25
Chocolate-colored limestone	3
Hard shelly blue limestone	2
Soft, blue limestone, crumbles easily	1
Blue, thin-bedded, limestone	3
Tonoloway limestone:	
Thin-bedded and platy limestone	20

Iroquois area.

The quarry of Mr. Lowe was operated in the extreme northwestern corner of Watts township across the river from the Iroquois station of the Pennsylvania Railroad. The limestone extends for a short distance to the east and it is possible that this outcropping was caused by the Perry County fault, which is visible along the northern end of the quarry. Here solution by water that found an easy passage along the fault plane has made a large cave. The Oriskany and the lower beds of the Helderberg are in contact.

From the top of the quarry one can see the Hamilton crossing the river on a southwest trend and having a southeasterly dip. In the quarry, however, the beds are practically horizontal.

A very hard and somewhat siliceous limestone about 12 feet thick forms the base of the quarry. About 50 feet above the base occurs a hard, slaty bed about 6 inches thick. Above this thin bed of slaty material the limestone is practically jet black and breaks with a distinct glassy fracture.

Most of the limestone is burned although some is pulverized. The thick overburden and poor transporting facilities have hindered the development. Grain brought such a low price during the summer of the reconnaissance that the farmers claim they were unable to buy lime to neutralize the soil. All these factors have hindered the development of the lime industry of Perry County.

JUNIATA COUNTY.

The Helderberg limestones of Juniata County extend in two continuous bands across the entire county from northeast to southwest.

The northern band enters the county at Richfield and runs westward through Cocolamus and McAllisterville, bending south at the latter village and outcropping about a mile north of East Salem. It then runs southwest for about ten miles to a point southeast of Mifflintown where it is sharply folded and extends across the Juniata River nearly to Allendale. From Mifflintown the outcrop on the south flank of the fold bends back to the northeast passing directly south of East Salem. The line of outcrop then reverses its direction and crosses the Juniata River at Port Royal where excellent exposures of it can be seen along Tuscarora Creek. It continues the southwestward trend past McCoysville and Peru Mills, leaving the county along the southwestern line.

The southern band enters the county east of Thompsontown and extends in a southwesterly direction, crossing the Juniata River near Mexico and passing through Pleasant View, and Honey Grove and leaves the county near Waterloo.

Tuscarora Valley area.

North of Honey Grove, the abandoned Allen quarry is located on the south flank of the most northerly of the two limestone ridges. The quarry has been but little developed. Bedding could not be seen, but farther to the east, the thin-bedded blue limestone dips into the base of the hill. The strike of the formation at this point is N. 45°E.

The bottom layers in the quarry are very hard and somewhat siliceous. Fossils are entirely lacking. The middle beds are more or less crystalline and deep blue in color. Few fossils occur in the middle portion, but above this more or less crystalline layer the beds are highly fossiliferous. All the fossils are poorly preserved. Among them are crinoids, corals, and a few brachiopods.

The old Allen quarry is probably the only good exposure in the western end of the valley. But in the eastern end of the same valley, the abandoned quarries in Turbitt and the adjoining townships show the Helderberg very well.

The first quarry in this area is located high along the hillside about one and one-half miles from Port Royal on the road to Ickesburg. In this quarry the beds appear to be quite massive and can be followed along the hillside for some distance. The pike cuts across the strike of the formations and shows them to be quite shaly. Along the road from Tuscarora Creek to the main highway from Port Royal to Ickesburg 32 different layers were counted in a thickness of three feet.

The second quarry is located along the same hillside about half a mile east of the road forks and here the rocks have apparently the same attitude as in the first quarry—strike N. 69°E. and dip 42° NW. The lower layers appear to be more or less rotten and gnarly but a deep cut along the hillside farther down the dip revealed massive beds of a blue gray to a gray fossiliferous limestone. There is considerable clayey matter present.

A kiln at the base of the hill shows signs of having being recently operated.

About 400 yards farther east and along the south side of the road, about 10 feet of strata are exposed. They show practically the same lithological features and attitude as noted above.

Along the south side of the road near Hertzler's store there is an excellent outcrop of the *Tentaculites* bed and the exact position of the Helderberg can be seen. Several rods to the east is a quarry in the Shriver chert member, and still farther east, the Oriskany is exposed in the railroad cut of the Tuscarora Valley railroad.

This formation can be traced across the Juniata River about one mile below Mexico station where it was studied in Benner's quarry.

In this quarry the main mass of rock has been extracted along the strike. Here the cut is 50 feet wide and runs practically due east-west. The rock for the most part is used for township road work although the immediate community is also supplied with burned lime.

The Hamilton quarry is one and one-half miles farther east and shows a thin, platy formation with beds averaging six inches to three feet in thickness. But as in the Benner quarry, the better grade of stone has been removed.

Mifflintown-McAllisterville area.

This area is about twelve miles long and when visited but one quarry was in operation. There are, however, eight abandoned quarries in the area which is located in Lost Creek Valley and the quarries have been developed in what is locally known as Firestone Ridge. This ridge is a westward continuation of Chestnut Ridge of Snyder County.

On the road from McAllisterville to Cocolamus, the Lennart quarry, now abandoned, shows two layers of a rather hard, blue limestone, about 25 feet thick. Included in the formation near the base is a 6-inch ledge of shaly material. The rocks dip about 15° SE.

Across the creek there are three abandoned quarries, Emey, Hoffman and Erisman-Smith. These were shut down but were to be operated in the following spring and summer. There are four old kilns on the properties and the people say that quarries in this section date back to 1797.

The upper layers in the Erisman-Smith quarry show a flinty overburden and are made up of grayish, impure limestone which contains few fossils. Directly beneath this grayish limestone there is a blue limestone about 15 feet thick overlying a more massive and blacker limestone which reaches a thickness of about 12 feet. This latter rock breaks with a distinct glassy fracture. Beneath it the limestone becomes somewhat siliceous.

The Slagle and Lighter (formerly the Land's) quarries, are on the south side of the ridge along the road to East Salem. Both have been abandoned.

The Slagle quarry shows about 25 feet of a shaly and slaty blue limestone. It has long been abandoned but the Lighter quarry is occasionally worked. In the latter. about 40 feet of dark blue to blue-black limestone is exposed. The quarry is about 100 feet long. Some fluorite is present and the rock is siliceous.

Following Lost Creek eastward along the northern flank of Firestone Ridge, one comes to the Foulkrod quarry. This was the only quarry in operation during the summer of 1921, when the study was made. Here the anticlinal arch of the valley can be seen, the southern flank being well exposed at the east end of the quarry, which is about 65 feet high and about 100 yards long.

Four kilns on the property were producing 16 tons of lime a week in 1921. The selling price of lime was then $7 a ton.

Section exposed in the Foulkrod quarry.[*]

Keyser limestone:	Feet.
Shaly limestone, not good for lime	8
Blue to black limestone, shattered	20
Blue gray limestone, very hard	1½
Bluish-black limestone ("quarry rock"), veins	35

The rocks dips 40° SE and quarrying is simplified by the shattering the rocks have suffered.

In that portion of the Lost Creek Valley where the limestone belt broadens out a quarry has been opened and then abandoned. The operator was a Mr. Stouffer. The beds exposed are practically the same as at the Foulkrod operation.

MIFFLIN COUNTY.

The Helderberg limestones of Mifflin County were studied only in a few places in the course of the present investigation. Considerable data have been taken from Report F3 of the Pennsylvania Second Geological Survey. These limestones extend entirely across the eastern portion of the county in two narrow bands that zig-zag in places due to intricate folding. There are also a few outliers. The northern belt runs in a rather straight line through Decatur Township to the Derry Township line where it turns eastward a mile due to a synclinal fold. It then turns southwestward, and crosses Kishacoquillas Creek and continues to the Huntingdon County line a short distance below Mt. Union.

The southern band is more regular. Entering from Snyder County, it passes southwestward forming a valley in which the towns of Wagner, Paintersville, Maitland, Lewistown, Strodes Mills and McVeytown are located. It crosses Juniata River a short distance below Hamilton.

Along the Kishacoquillas Creek near Lewistown two divisions were noted by the geologists of the Second Geological Survey. The upper is about 140 feet thick and consists of flaggy argillaceous limestones that have been quarried somewhat for building purposes. Some lime has been made from them but it is of poor quality. The lower member about 185 feet thick, is composed of more massive beds of blue limestone and has been called the Lewistown limestone by the Second Geological Survey. This member has been quarried extensively for lime and in the past for furnace flux, especially the upper 60 feet that represents the best grade.

Reeside[37] has studied this region in detail and has published the following section.

Section on Kishacoquillas Pike, at Mount Rock, Lewistown.

	Thickness in feet
Helderberg limestone:	
New Scotland limestone member:	
Limestone, very dark, impure, fissile	3.0
Shale, weathered brown, very fissile; contains some bands of very dark impure limestone	10.4
Limestone in two beds (12 and 9 inches) separated by shale (9 inches), fine grained, blue-gray, crystalline	2.5
Limestone, single bed, light gray, cherty, fine grained; some calcite cleavage faces show; does not scratch hammer	2.6
	18.5
Coeymans limestone member:	
Shale, weathered, brown	.6
Limestone, single bed, light gray, cherty	2.3
Shale, weathered, dark gray, calcareous; limestone bands and large nodules	1.5
Limestone, massive, sandy, crystalline, blue; some black chert nodules; very tough, hard rock	6.2
	10.6
Keyser limestone member:	
Limestone, dark gray, fine grained, thin bedded	1.0
Limestone, massive, dark gray, fine grained; conchoidal fracture	2.0
Limestone, shaly, yellow, weathered	1.0
Limestone, massive, dark gray, impure, fine grained; conchoidal fracture	2.5
Shale, weathered	2.0
Limestone, light gray, solid, fine grained; conchoidal fracture	1.0
Limestone, platy, dark gray, impure	3.0
Concealed	5.1
Limestone, platy, light gray, impure, fine grained; conchoidal fracture	2.0
Concealed	6.2
Limestone, impure, platy, yellow; weathered much and poorly exposed	3.8
Limestone, platy, impure, weathered, yellowish	4.0
Limestone, massive, light gray; conchoidal fracture	1.5
Limestone, thin bedded (2 inches), dark gray; conchoidal fracture	.5
Concealed	16.6
Limestone, banded; conchoidal fracture	.5
Concealed	1.0

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[37] Reeside, J. B. Jr., Helderberg limestone of Central Pennsylvania: U. S. Geol. Survey Prof. Paper 108, pp. 212-214, 1918.

Keyser limestone member—Continued.	Thickness in feet.
Limestone, very impure	2.0
Limestone, thin bedded, fine grained, dark gray, impure, poorly exposed	4.0
Limestone, impure, dark gray, thin bedded, fine grained	4.3
Concealed	5.9
Limestone, very shaly, with purer fine grained light-gray bands	2.8
Limestone, very coarsely nodular (4 to 6 inches), light blue-gray; conchoidal fracture. Shale between nodules	3.2
Limestone, thin bedded, blue-gray, crystalline	2.9
Limestone, massive; in part light blue-gray, fine grained; in part subcrystalline	2.4
Limestone, thin bedded (2 to 6 inches), fine grained, light bluish gray; conchoidal fracture	7.1
Limestone, impure, shaly, alternating with harder layers, each in about 6-inch courses	3.4
Concealed	4.2
Limestone, shaly, impure, with hard layers of more resistant rock	1.7
Limestone, dark gray crystalline	5.1
Limestone, thin bedded (1 to 6 inches), light blue-gray, fine grained, impure; has shale laminae between the layers and several small lenses of brown weathered chert	5.8
Limestone, massive, nodular, impure, dark gray	8.3
Limestone, massive, dark gray, impure, not very nodular	4.1
Shale, weathered, yellow	0.5
Limestone, very nodular, impure, shaly, gray; many of its fossils are silicified	2.4
Limestone, massive, somewhat nodular, dark gray, subcrystalline, impure	2.8
Limestone, very nodular, impure, dark gray, weathered	1.8
Limestone, massive, not nodular, dark gray, coarsely crystalline	1.6
Limestone, nodular, impure, weathered; bastard limestone with occasional thin lenses of black chert	2.6
Limestone, crystalline, dark blue, thin bedded, with shaly laminae	2.0
Limestone, crystalline, dark blue, pure, massive, not nodular	1.9
Limestone, weathered, very nodular	4.4
Limestone, massive, blue gray, coarse, crystalline, crinoidal; weathers thin bedded in upper part	9.4
Limestone, single massive bed, pure, dark gray, coarsely crystalline and crinoidal in part; fine grained and curly in other parts	6.2
Limestone, nodular, impure, weathered; crystalline on fresh fracture and blue-gray	.9
	157.9

Tonoloway limestone	Thickness in feet.
Limestone, rather massive, fine grained, pure, dark gray, almost a blue-black; conchoidal fracture	6.4
Limestone, thin bedded (1 inch); much like unit above, but less massive and resistant; looks fairly solid where entirely unweathered; pure	13.4
Limestone, solid-looking, heavy bedded, gray	5.0
Shale, weathered	.5
Limestone, fairly solid, gray, in three beds (18, 12, 12 in.) separated by shale	3.5
Limestone, gray; weathers into small blocky fragments and has a somewhat nodular appearance	4.0
Limestone, thin bedded, gray	2.0
	34.8

Lewistown area.

The limestones have been most extensively quarried near Lewistown and between Lewistown and Reedsville. In this vicinity the Logan Iron and Steel Company formerly worked a large quarry that contained 60 feet of excellent stone for flux. A partial analysis gave the following results: SiO_2 1.580, Al_2O_3 1.004, Fe_2O_3 .237, P .016.

One mile north of Lewistown the Mifflin County Lime and Stone Co. is operating a quarry to obtain stone for agricultural lime and for road metal. A considerable part of the stone is high in silica. Nearby the Lewistown-Reedsville Trolley Co. is working a quarry in the same beds for crushed stone for concrete and highway construction. Most of the stone is excellent for this purpose as it is hard and tough and certain beds are siliceous. There are a few shaly beds present.

At and near Maitland Gap several quarries have been worked for lime. At the quarry of John Goll six samples taken from the 65-foot thickness of good stone in massive beds gave the following results when analyzed by the Cambria Steel Co.:

Analyses of Helderberg limestone near Maitland Gap.

	Range	Average
$CaCO_3$	94.77 to 97.00	96.00
$MgCO_3$	1.03 to 1.99	1.50
SiO_2	0.76 to 2.26	1.15
Al_2O_3 } Fe_2O_3 }	0.40 to 1.04	0.70
S	0.02 to 0.12	0.045
P	0.004 to 0.009	0.006

These beds overlain by shaly limestone and underlain by shaly cherty limestone dip into the hill and could only be worked extensively by underground mining. The same beds are exposed all the way to Paintersville.

Westward the Helderberg limestones have been quarried in many places between Lewistown and McVeytown and in fewer places in the southwestern corner of the county near Hamilton.

SNYDER COUNTY.

The Helderberg limestone enters Snyder County on the flanks of the Selinsgrove arch and is best exposed along the main line of the Pennsylvania Railroad below Selinsgrove Junction. This locality is described under the Northumberland County area. The formation runs in a thin band westward through Selinsgrove and Middleburg, turning to the southwest through Beavertown and out of the county.

The southern strip runs through Freeburg, Freemont (Mt. Pleasant Mills) and Richfield. A bit of limestone is exposed in the area of McKees Half Falls. There are no quarries in this strip which is on the Dalmatia axis.

Selinsgrove area.

In Penn Township directly north of the town of Selinsgrove, the Pennsylvania Lime and Stone Company operates a large quarry which is about 200 feet long and 60 feet high. In the middle portion, where the highest elevation is reached, numbers of nodules were found.

Many shale beds are intercalated with the good limestone, making it quite difficult to quarry. A hard siliceous limestone which is very hard to break with the ordinary blow of the hammer runs uniformly through the quarry. Upon breaking open some of the nodules, which are quite numerous, many fossils were found. These were, however, in such a mutilated state that no identification was attempted. In the west end of the quarry the rock crumbles readily, breaking with a glassy fracture under the least blow.

The nodules for the most part are made up of a heavy, hard, gray limestone which is enclosed in a rather impure, bluish limestone, highly fossiliferous. Many clay seams and clay pockets are found. Bedding planes are obscured.

Although most of the rock is burned, this quarry was supplying stone for the State road from Middleburg to Selinsgrove, at the time of our visit. The quarry which was opened in 1861 turns out about 80 tons of crushed stone per day. The equipment consists of a jaw crusher and three-size trommel. Mudcapping, steam drilling, and hand sledging are the quarrying methods employed.

Middleburg area.

There are two quarries in this area, one south of the town and the other northeast. The first quarry, opened in 1919, is operated by D. J. Stahl. About 25,000 bushels of lime are burned monthly. The crushing equipment includes a Jeffrey crusher and turns out 100 tons of stone per day.

Section in the D. J. Stahl quarry, Middleburg.

	Feet.
Keyser (lower) limestone:—	
Thin-bedded, blue-gray limestone	10
Dark, gnarly, thin-bedded limestone	15
Blue-gray limestone, with no fossils	12
Hard-gray limestone (road material)	....

The quarry face is about 45 feet high with a 100 foot breast. It is operated with compressed air drills and hand sledges. Gravity traction is used to convey the cars to the jaw crusher.

The quarry along the road to Selinsgrove south of the town is owned by Dr. Zechman. The State Highway Department to which it was leased has installed a portable crushing plant.

Section exposed at the Zechman quarry, Middleburg.

	Feet.
Thin-bedded, shaly, fossiliferous limestone	6.0
Thin streak of gnarly limestone	0.5
Massive limestone	10.0

The Zechman quarry was opened in 1895 and is about 24 feet high and 100 feet long. The output is 200 tons per day.

Lime Ridge.

This ridge is formed by an anticlinal arch which is well exposed in all the quarries near the town of Freemont (Mt. Pleasant Mills P. O.) The ridge runs in a southwesterly direction for about ten miles. It is bordered on the north by Hiester Valley and on the south by Firestone (Flint) Ridge. The only working quarries are in the Freemont area directly south of Mt. Pleasant gap and farther west along the ridge in the Richfield area, where the strip enters Juniata County.

All the quarries of the Lime Ridge group are small ones of about 60 foot frontage and 40 to 60 feet high. All are on ground leased from Mrs. Cyrus Arbogast.

The operators along the ridge from east to west are, George Dry. Irvin Potteiger, Irvin Boyer, who operates three quarries, Mrs. Joseph Heim, William Dresser-Abner Hoffman, Mrs. Cyrus Arbogast, and John Stock-William Phillips.

Along the north side and near the east end of the ridge there are many abandoned quarries. The formation pitches into the hill on a 60° SE dip and maintains a strike of N 80°E. The only working quarries at the time of the visit were the Boyer and Phillips-Stock quarries.

The lower beds of the quarries appear to be in good stone. They supply two kilns in the Boyer operation and one in the Phillips-Stock.

Boyer quarry. The lower beds are best exposed. The stone is hard, grayish blue and weathers to a steel gray. An estimate of the thickness could be made only by measuring the cut along the strike where the stone has been extracted. This cut was 45 feet wide. The gray bed is interleaved with thin, dark beds and the rock breaks with a fracture. Some of these black rocks show slickensided surfaces. There are also some calcite veins but the grayer beds contain much vein material. The gray rock, when massive, breaks with a peculiar flat surface which is not unlike a cleavage plane.

The upper beds, along the western end of the quarry, have been greatly shattered along the axis of the anticline, showing a somewhat pitted surface. There are numerous calcite veins paralleling the bedding planes. The surface is about 35 feet high, being quite shaly and badly weathered and shows much clay in seams and in the overburden.

The face is a long continuous one including the second quarry which is a few rods to the west, and which has been abandoned. The gray rock here is not exposed and hence could not be measured.

The main quarry rock of the Boyer operation is a thin, bluish-black limestone which contains numerous fossils. Here, the whole anticline is exposed and the northern beds have a steep dip, while the dip to the south is only slightly perceptible. Shaly beds and many calcite veins are in evidence along the northern flank.

The quarry is being driven along the axis of the anticline, as by virtue of the shaly character of the beds, but little blasting is required to dislodge the stone. The cars are run down a gravity plane to the kiln.

Mr. Boyer has recently drilled a test hole and finds good limestone for a depth of 45 feet. Most of the lime in this quarry, however, burns to a peculiar reddish hue.

The fourth, fifth and sixth openings have been made along the same line of outcrop and have been long abandoned. The seventh quarry is worked intermittently.

The two operated by Phillips and Stock were active at the time of the visit. They showed a combined face of 300 feet and were about 30 feet high. The kilns produced approximately 300 bushels of lime per day.

The lower beds, well shown in these quarries, are about 20 feet thick and made up of more or less massive limestone. The layers of this massive material average about 18 inches thick. These in turn, are overlain by a shaly limestone which reaches a thickness of about 8 feet. There are many calcite veins and clay pockets in the beds of this quarry.

UNION COUNTY.

The Helderberg limestone outcrops in four separate areas in this county. The most northerly exposures are in Gregg township where the band has an east-west course. At Lewisburg the formation loops around a structural basin running four miles west of the town and swinging back eastward across the Susquehanna River two miles north of Lewisburg. This same strip of limestone runs east to Berwick, Columbia County and then swings back westward entering Union County at Winfield. One isolated area of thin limestone includes the Swengel and Mifflinburg district.

Gregg Township.

The area in this most northerly township of the county includes a part of the White Deer Valley and has but one working quarry. This is operated by Galloway and Meek. It is in a synclinal basin the axis of which crosses the wagon road about four miles west of Allenwood.

A thin, shaly limestone forms the north-northeast wall of the quarry, and a fairly good lime is obtained from it. There are numerous reddish clay seams in the overburden and also in the overlying grayish limestone, which reaches a thickness of 40 feet. This gray limestone is underlain by a more bluish limestone about 20 feet thick. It breaks with a distinct glassy fracture.

Swengel area.

The next operation visited is in the central part of the county. This small area includes the town of Mifflinburg and west to Swengel, where the limestone pinches out.

At Swengel, there are numerous small operations, all on the north side of the ridge. At this point it would be well to mention the fact that the economic value of the burned lime in this section is greatly lessened by the "cut-throat" methods of the various small operators. Lime was sold at 9 cents a bushel during the summer of 1921, while in other areas where larger operators were at work, lime ranged from 17 to 28 cents a bushel.

At the quarries the men constantly refer to the so-called "bastard" limestone a name which was used frequently in the literature during the time of White, Platt, d'Invilliers, and others. The rock is a more siliceous limestone. Here the so-called "bastard" limestone overlies the good black limestone which could be easily quarried by benching into the hill in the lower portion.

The operators from east to west are:—Knauss Brothers, C. R. Ruhl (2 quarries), J. C. Coleman, C. R. Ruhl, Charles Dorman, C. R. Ruhl, D. H. Catherman, and the township quarry. The quarries working at the time of the visit included the Knauss, Dorman, and township operations. The outcrop can be traced for a quarter of a mile along the hillside. The quarries have been in operation for the past 25 years. The total output is about 2500 bushels per week.

The basement rock of the Swengel quarries is a black limestone with some calcite veins. The thickness could not be estimated because of the overburden. The lowest bed being worked is about 4 feet thick. It is quite siliceous and is overlain by a thin-bedded, somewhat shaly rock about 10 feet. Above this shaly bed, a dark blue limestone occurs, which in places is somewhat gray, grading into a shaly limestone. Many caves have been broken into in the course of quarrying.

The extreme western outcrop where the township quarry is located shows limestone to a thickness of 20 feet. For the most part it is a grayish-blue limestone, weathering buff and showing many poorly preserved fossils on the weathered surfaces.

Mifflinburg area.

In the quarry of the Limestone Products Company, which is on the ridge directly south of the town of Mifflinburg, the same beds as those described in the Swengel area are found. They are better exposed.

Here the stone is crushed for road materials, and some of it is burned for lime. At the time of our visit the quarries of the district were furnishing stone for the State road to Bellefonte.

Section exposed in the Limestone Products Co. quarry.

Keyser limestone:	Feet.
Thin bedded, more or less shaly limestone	10
Bluish gray hard limestone	20
Massively bedded limestone	36
Blue to black limestone	12
Shaly limestone	7

Farther west, but in beds represented by White's Lewistown limestone are the quarries of J. P. Miller and the abandoned quarry of Emanuel Snyder.

Section exposed in the J. P. Miller quarry.

	Feet.
Shaly and thin-bedded limestone	12
Massive blue limestone	10
Hard, siliceous limestone	12
Black limestone (thickness determined by diamond drill)	35

Section exposed in the Emanuel Snyder quarry.

	Feet.
Shaly limestone in very thin beds	10
Blue limestone, irregular fracture	20
Bluish gray limestone, massive	20
Blue limestone, smooth and good quality	8
Fine-grained limestone, two-foot beds	6
Gray, shaly limestone in base of quarry	10

The strike of the rocks in this locality is almost due east and the dip 24°S. *Crinoids* and *brachiopods*, poorly preserved, were found in abundance in the Snyder quarry. The Miller quarry shows large joint planes, many clay seams and pockets.

Winfield area.

The Winfield quarry is about half a mile southwest of the town of Winfield. It is the largest operation in the county and one of the largest visited in the entire study of the Helderberg. The quarry is about a quarter of a mile long and the face reaches a height of 100 feet. The beds pitch steeply to the south at an angle of 54° and strike N 84°E.

The output when visited was 1200 bushels of lime per week and as needs arise the quarry has a total capacity of 750 bushels daily. There is a battery of 15 kilns on the property.

Section exposed in the Winfield quarry.

	Feet.
Shaly limestone	6
Thin, massive limestone, beds 10 inches and thicker	27
Massive seamy limestone	8
Massive blue limestone, solid beds	5
Grayish blue limestone, in thin beds	8
White to bluish limestone	6
Shelly limestone	6
Thin beds of blue limestone 3 to 6 inches thick	5
Blue limestone of good quality	3
Thin beds of blue limestone	7
Smooth blue strata with thin slate in center	8
Good blue limestone	10

The so-called "bastard" limestone constitutes the series from the shelly beds upward.

At an abandoned quarry 1½ miles west of Winfield the following section was observed.

Section in quarry 1½ miles west of Winfield.

	Feet.
Blue beds, generally under one foot in thickness	25
"Bastard" shelly limestone	6
So-called "plaster" beds	35

NORTHUMBERLAND COUNTY.

The Helderberg limestone first appears in the northern part of this county about three miles south of the northern border, just north of the town of Dewart, on the Susquehanna. Its course is a general southeastern trend, passing south of Turbotville, to the Montour County line. Then it swings back and follows a southwestern trend, outcropping all along Limestone Ridge, particularly in the neighborhood of Limestoneville, and continues westward to the south side of Milton. It turns back in Union County and follows the north side of Montour Mountain from Montandon eastward. Another belt is continuous across the county from near South Danville to the river just north of Northumberland.

Another strip of outcrops of the Helderberg is found 2 to 3 miles south of Sunbury, and still another between Dalmatia and Urban.

The limestone of the Upper Salina is in places difficult to differentiate from the true Helderbergian series and in some instances is included in the series.

The chief quarries in the county are in the Turbotville, Herndon, and Dalmatia areas. These quarries were all operating during the summer of 1921 and most of their product is burned lime, although a great deal of the material was used as ballast on State highways then under construction in the vicinity of the quarries.

Turbotville area.

The town of Turbotville in Lewis township, on the Berwick Branch of the Pennsylvania Railroad, is the chief quarry area of the county.

The limestone ranges from a dark, rather slaty limestone belonging to the Tonoloway formation to the more massive and fossiliferous, and in places, nodular limestone of the Keyser formation. At various localities the Keyser formation was seen.

The following quarries were visited: A. P. Yerg, Cyrus Geissinger, Showers, Evans, and the abandoned Williamson quarries.

The A. P. Yerg quarry, operated for the Horst Construction Company of Chicago, is about 75 feet high and about 300 feet long and has but a few inches of overburden. Mud-capping and hand-sledging are the methods used in this quarry. About 25 men were employed during the busy season. A motor-dump conveyor was used to carry the blasted stone to the crusher. The quarry output is about 175 tons of crushed stone per day.

Section exposed in the A. P. Yerg quarry.

	Feet.
Keyser limestone:	
Shaly limestone, beds from one to three inches thick	7
Bluish gray limestone beds ranging from 1 inch to 4 feet thick	10
"Cement" beds, dark blue to black	6
Gray to grayish blue limestone	20
Dark blue to black limestone used for road ballast	15
Tonoloway limestone:	
Shaly and platy limestones	?

Small fossils, weathered casts and calcite veins were found in abundance in the weathered upper portions of the quarry.

The Cyrus Geissinger quarry, which is approximately 60 feet high and fully 500 feet long, is directly over the hill south of the Yerg operation. The overburden is deep. The limestone is practically the same as in the Yerg quarry. The chief bed is a very dark to almost black limestone which has a characteristic glassy fracture and is about 15 feet thick. It is made up of beds that average a foot in thickness. A bed called "niggerheads" overlies the black limestone and is about eight feet thick. It corresponds with the so-called "cement" beds of the Yerg quarry. Above the "niggerheads" is one foot of shaly limestone. This latter bed contains many shale laminae. The shaly beds alternate with a bluish to gray massive limestone. The rock weathers to a buff yellow. No fossils were found. Most of the product is burnt for lime.

The quarries for the most part show an upper limestone which is quite shaly and in some places quite sandy. The beds average about one to two inches thick and make up a total of six feet. It overlies a massive, blue-gray limestone which is directly above a harder and more massive layer of blue limestone. This latter has been erroneously termed a "cement" bed by the district quarrymen. It does not produce good lime.

Under the so-called "cement" bed the blue gray limestone comes in and represents the Stormville of White. This is probably the middle Keyser of Reeside. It is directly above the blue and flaggy limestone of the Geissinger quarry, and is present also in the abandoned Williamson quarry where samples for chemical analysis were obtained. The analyses showed 92 per cent calcium carbonate with less than 3 per cent magnesium carbonate.

Milton area.

The limestone quarried here is also the Tonoloway, and is found on the north slope of the Milton sub-axis. It is not quite as pure in this particular locality. Because of this fact most of the quarries opened in this area have been abandoned. The ones that have continued operation are crushing the material. The only quarry working during the summer of 1921 was the Milton borough quarry.

The upper portion of the borough quarry shows a very crumbly limestone and contains some thin beds of massive pure limestone. On tracing this bed across to a neighboring quarry it was found that the *Stromatopora* bed appeared, hence this quarry is in the Keyser. To the north end of the quarry the platy and shaly beds of the Tonoloway appear. There are numerous clay veins and pockets, as well as much cave material. There are also many calcite veins.

Borough of Milton quarry. The main part of this quarry is being driven into a shaly limestone. The lower part of it is hard and black. Above this black bottom layer there is a grayer rock which breaks into fine pieces, somewhat angular, and with a glassy fracture. This bed is eight feet thick. It in turn is overlain by a more or less chocolate-colored bed of about the same thickness. This bed, however, is more massively bedded.

Between the three massive beds the rock is quite shaly, and the beds are from one to two inches thick. In the upper part of the quarry the rocks are deeply weathered, which probably is responsible for the shaly appearance of the beds. Clay pockets up to one foot thick appear in the rocks. Calcite veins are quite numerous. From all appearances the quarry is along the southern outcrop of the Helderberg.

Pick and shovel methods are used in the quarry and the caving of overlying rock by means of undermining in the clay seams, makes the cost of operation quite low.

There are a few quarries on the road from Milton to Limestone Ridge. In one of these which was operated some years ago by Natt Clemmens, the weathered *Stromatopora* bed stands out in excellent relief. This quarry supplied the entire neighborhood and furnished stone for several kilns. It was opened in 1900.

The Milton borough quarry is along the same line of strike as the Clemmens quarry but higher in the formation. The *Stromatopora* bed is not visible in the former quarry.

There seems to be a regular alternation of massive and thin-bedded limestone throughout the entire region. These shaly limestones separate the darker limestones from the gray. The gray beds are decidedly harder and more massive. The average shaly beds seem to be about 10 inches thick and make up a total of 10 feet. They are best seen along the eastern end of the quarry where they grade into a powdery yellow rock, which is quite sandy. No fossils were found and the fact that the *Stromatopora* bed occurs below this and the alternating beds leads the writer to the conclusion that this is the upper Keyser of Reeside and the old Stormville of White.

At Selinsgrove Junction below Sunbury there is a fine exposure of the Helderberg. Reeside[38] has published the following detailed section of this locality.

Section of south side of anticlinal axis at Selinsgrove Junction.

	Thickness in feet
Oriskany formation:	
Sandstone, cherty, fine grained, ferruginous	4.0
Concealed	10.9
Sandstone, cherty, fine grained, ferruginous	7.1
Concealed	
Limestone, dark gray fine grained, very arenaceous; numerous 1-inch chert lentils	12.0
Shale, dark brown	
Limestone, dark gray fine grained, very arenaceous; numerous 1-inch chert lentils	12.0
Shale, very sandy; breaks into flat fragments; dark gray to chocolate-brown	5.4
	54.4
Helderberg limestone	
New Scotland limestone member:	
Limestone, very impure, dark gray, mottled with yellow; weathers into small irregular fragments some of which are siliceous	8.6
Lime shales, dark gray, with a few thin limestone layers; weathers to thin laminae	35.8
Limestone, massive, crystalline, arenaceous, dark gray	9.0
Limestone, in large nodules (diameter 6 to 8 inches) embedded in a shaly matrix	4.2
	57.6
Coeymans limestone member:	
Limestone, fairly massive, coarse, blue-gray, arenaceous, interbedded with layers of black chert 3 to 4 inches thick; joint planes show large imperfect crystals of calcite and quartz	3.6
	3.6
Keyser limestone member:	
Limestone, thin bedded, (1 to 3 inches), blue, fine grained	5.5
Limestone, blue, fine grained, with conchoidal fracture; courses 6 to 12 inches, separated by about the same thickness of gray calcareous and arenaceous shale	6.9

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[38] Op. cit., pp. 220-224.

	Thickness in feet.
Keyser limestone member—Continued.	
Shale, yellow	1.4
Limestone, heavy bedded, massive, impure, light gray indistinctly laminated	18.3
Limestone, medium bedded, impure, light gray; a few layers very shaly and weathered; toward upper part the bedding planes weather out clearer and rock is laminated; not distinctly separated from underlying unit	17.1
Limestone, thin bedded (1 to 2 inches); some layers crystalline, pure, blue, fossiliferous; others impure and shaly	3.5
Limestone, finely crystalline, light bluish gray, in two solid beds separated by 8 inches of shaly limestone	3.2
Limestone, pure, fine grained, thin bedded (3 to 8 inches), blue; breaks with conchoidal fracture, though a few layers are platy and impure; layers are separated by thin shale	7.8
Shale, weathered, yellow filled with small lenses of crystalline blue limestone.	2.1
Limestone, medium bedded (10 to 12 inches) fine grained blue, with conchoidal fracture; platy in parts; a few fossiliferous lenses.	7.8
Limestone, very shaly, light gray to yellow, with a few thin pure streaks.	19.8
Limestone in 3 to 6 inch courses separated by about 18 inches of lime shales. The shales are light gray to yellow; the limestones are in part fine grained, in part crystalline. Layer with much pyrite.	6.6
Limestone, extremely massive; nodular character not nearly so distinct as in the unit below; coarse crystalline lenses abundant.	9.0
Limestone, extremely massive, nodular, dark; nodules pure; matrix earthy, gray; basal 2 feet has in many places a rude columnar structure and is not nodular; upper 2 feet only faintly nodular.	13.6
Limestone, impure, nodular; looks sandy but contains no sand.	1.2
Limestone, rather heavy bedded, blue-gray, with conchoidal fracture; nodular character pronounced.	3.4
Limestone, thin bedded, otherwise like the unit above.	3.2
Limestone, very nodular, thin bedded, fine grained, dark gray.	4.0
Limestone, very nodular, more or less impure, dark gray. Some benches much more shaly than the remainder and weather back faster. No other bedding noticeable.	19.4
Limestone, nodular, dark gray, fine grained; impure looking on fresh fracture; in places inseparable from the unit below, but apparently not a stromatoporoid bed.	3.0
Limestone, made up entirely of stromatoporoids.	6.0
Limestone, very nodular, fine grained, thin bedded, bluish gray. Bryozoa throughout.	6.0
Limestone, single bed, dark gray, fine grained with conchoidal fracture; very distinct along exposure; not nodular	.9

	Thickness in feet.
Limestone, thin bedded, dark gray, nodular, impure.	2.5
Limestone, massive, blue-gray, somewhat nodular; bounded where measured by prominent bedding planes.	6.0
Limestone, thin bedded (1-inch courses), with shaly laminae between the layers; very nodular. Some layers dense, bluish gray, conchoidal; others subcrystalline; others earthy.	15.1
Limestone, like the unit above but somewhat less nodular.	5.2
Limestone like the above two units but less nodular still.	3.8
	202.3
Tonoloway limestones:	
Limestone, massive, dark gray, conchoidal, fine grained; quarried for lime.	4.8
Limestone, thin bedded, medium gray, fine grained, with conchoidal fracture; quarried.	3.0
Limestone, solid, dark gray, with conchoidal fracture; quarried just behind some old limekilns by a long cave-like opening.	8.2
Concealed.	4.0
Limestone, banded, dark, impure; has a very noticeable rude columnar structure.	14.4
Limestone, dark gray, fissile, banded; contains large geodal calcite masses. In some parts a fine reticulated structure weathers out, due perhaps to silicification along close joints.	17.0
Limestone, light gray, siliceous, knotty.	1.0
Limestone, rather platy, crystalline, light gray; many stringers and spots of calcite and some small geodes; weathers to thin laminae.	10.0
Limestone, fairly pure, dark gray, fine grained, conchoidal; in thin lenses separated by very shaly impure layers.	6.5
Limestone, very light gray to yellow; impure; conchoidal fracture; apparently not much weathered.	3.0
Limestone, oolitic, siliceous, dark gray	.5
Shale, laminated, light gray; thicker layers very light gray on fresh fracture.	11.2
Layer of irregular geodal calcite masses.	.5
Shale, laminated, light gray.	9.8
Limestone, fairly massive, dark gray, fine grained; conchoidal fracture.	8.2
Limestone, platy, dark gray.	1.0
Limestone, light gray, knotty.	3.0
Limestone, very platy, laminated; light gray on weathered surface; dark, impure, earthy on fresh fracture; some layers finely crystalline.	4.8
Limestone, light gray; banded on weathered surface; dark, conchoidal, resinous on fresh fracture; solid bed; very fine grained.	3.2
Limestone, mostly concealed by talus.	10.0
Limestone, banded, gray; breaks into thin, papery fragments.	4.0

	Thickness in feet.
Limestone, banded, yellowish	3.5
Shale, yellow, weathered	2.0
Limestone, massive, banded, light gray	6.0
Shale, brown, weathered	1.8
Limestone, blue, sandy-looking, massive; apparently very impure; breaks into irregular fragments	7.0
Concealed to the level of the railroad at the axis of the anticline, about 35 feet	
	148.4

Dalmatia area.

This area of limestone is lenticular in shape, outcropping in a valley about three-quarters of a mile wide and six miles long. The limestone crops out in an almost east-west direction for about six miles. It is the eastern end of a canoe-shaped structure. About half a mile north and across the mountain there is a somewhat similar outcrop of the Helderberg but it is of lesser dimensions.

In the second strip are located the quarries of Heber and Urban, but none were in operation during the reconnaisance.

About half a mile north of the town of Dalmatia, formerly called Georgetown, is the abandoned quarry of Elmer Radel. The growth of weeds shows that it has not been used for some time. In this quarry, however, the northern flank of the anticline is seen. The rocks are buff to blue, and rather impure. The beds are somewhat massive and are about 40 feet thick. Here again the so-called "Bastard limestone" of White appears. It is 30 feet thick.

Between Dalmatia and Hickory Corners there are several abandoned quarries most of which are brush grown and contain abandoned kilns. The quarries of a Mr. Long, William Phillips and one other, the owner of which could not be ascertained, are on the southern flank of the anticline. The quarry of Elias Phillips is across the valley on the north side and has been abandoned.

The largest abandoned operation seen in the valley is the old quarry which was worked by Mr. Sieman and Philip Klinger. It is on the north side of the valley and is about 500 feet long in an east-west direction. At the extreme western end of the quarry the beds dip 75° from the Dalmatia axis. Due to the tremendous shattering along the axis the beds appear to be quite thin. They are well weathered to a dull yellow. These beds are about 25 feet thick and abound with poorly preserved fossil forms.

Above this band of shattered limestone there are veins of pure white calcite which can be traced throughout the valley. Several fossil zones, including the *Chonetes jerseyensis* zone, were found and these seemed to alternate with the calcite veins.

About two feet above the last fossil horizon there is a rather gnarly bed of limestone which breaks into angular pieces, and which is scantily fossiliferous. The *Chonetes jerseyensis* zone and the *Stromatopora* bed of the Keyser are exposed in this abandoned working. To the east the calcite veins lose their parallelism and their characteristic cross-cutting. Ruins of twelve kilns are on the property.

Many small operators were at work in the Dalmatia area.

On the road to Mandata (Bull Run), across the valley and beyond the schoolhouse on the right side of the road, is the quarry of Mr. Hepner. About a quarter of a mile farther east there is another Hepner quarry. Both of these quarries have been worked along the strike and show the thickness of the good limestone to be about 40 feet.

The beds here dip about 53° NW and strike N 82° E. The beds at the western end of the quarry are gray and have numerous calcite veins. This limestone is underlain by a grayer limestone which is more massive and contains many calcite veins. Some purple fluorite was found here. Some of the upper beds show graphitic slickensided surfaces.

Along the southern end of the quarry there is a broad, flat face of black limestone which also shows excellent slickensided surfaces. This marks the contact of the Keyser and the Tonoloway formations. It is a distinct contact.

This particular quarry is operated by Edward Hepner and was formerly the property of Gabriel Adams, who opened it in 1842. Mr. Hepner burns about 2500 bushels of lime a month.

About a quarter of a mile farther north along the road to Mandata is the quarry of the elder Hepner. It is in the same ridge as the Urban quarries and along the same line of strike as the other Hepner quarry. It shows practically the same features as the former except that the rock tends to become more massive and breaks with a characteristic glassy fracture. The elder Hepner was intending to install a pulverizer.

The Dalmatia axis crosses the Pennsylvania Railroad Northern Central Division north of the town of Dalmatia. It is one of the type localities chosen by Reeside.[39]

Section 1 mile south of Dalmatia

	Thickness in feet.
Helderberg limestone:	
New Scotland limestone member:	
Concealed by wash, filled with yellow-brown ochery shale and much chert.	6.4
Shale, ochery yellow, fissile, fine grained.	1.5
Concealed interval; clay and soil filled with fragments of weathered brown ochery shale and sandstone; a little chert observed.	13.7
	21.6

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[39] Op. cit., pp. 217-220

	Thickness in feet.
Coeymans limestone member:	
Limestone, coarse, dark gray, very sandy; weathers to resemble a brown ferruginous sandstone; contains black chert lentils; no fossils observed.	2.0
	2.0
Keyser limestone member:	
Limestone, banded, fine grained, with conchoidal fracture, in 2 to 4 inch layers, separated by same thickness of weathered yellow shale; contains near top some large, irregular curly masses (18 inches in diameter), which look somewhat like *Stromatopora*	10.3
Limestone, blue-gray, conchoidal fine grained, in four layers (8, 10, 3, 10 inches) separated by platy yellowish limestone.	3.3
Limestone, banded, fine grained, extremely platy, yellow on weathered surface, light gray on fresh fracture; calcite seam at top	5.7
Limestone, blue-gray, fine grained, conchoidal, thin bedded (6 inches); scattered lentils of black chert (1 inch thick and 18 inches long); calcite sheet at 118.6 and top.	2.9
Limestone, bluish, fine grained; conchoidal fracture; in thin layers (1 to 3 inches), with shale laminae between; calcite sheets.	12.1
Limestone, very impure, dark, shaly; carries irregular lenses (2 to 3 inches in diameter) of pure bluish limestone; in bulk about half of each; weathers to a light-gray color; calcite seam near base and at top.	6.0
Limestone, pure, thin bedded, fine grained, bluish gray; conchoidal fracture; some fossiliferous lenses.	1.7
Limestone, coarse, blue-gray, crystalline, in irregular 2 to 3 inch layers with light-gray shale laminae between; calcite sheet near top.	3.2
Limestone, shaly, weathered, impure, dark gray; contains a few pure crystalline streaks; calcite sheet near top.	1.9
Limestone, coarse, crystalline, bluish gray, profusely fossiliferous.	0.4
Limestone, solid, impure, dark gray; weathers yellow; contains many streaks of pure fine-grained limestone; calcite sheet at top.	2.0
Limestone, coarse, crystalline, blue-gray; weathers light gray; profusely fossiliferous.	2.3
Limestone, impure, medium gray, fine grained; weathers brown and has a number of thin conchoidal purer lenses which weather light gray; calcite sheet at base; solid unit as a whole.	3.9
Limestone, blue, crystalline, in lenses 1 to 2 inches thick, with irregular shaly layers between; shale weathers yellow; limestone gray.	2.2
Limestone, in four layers; blue, conchoidal, fine grained; crystalline fossiliferous streak, shale laminae between layers.	2.5

	Thickness in feet.
Shale, calcareous; light gray and yellow on weathered surface, dark gray on fresh fracture; has a diagonal "shear" parting and is interleaved with numerous thin beds of pure blue-gray crystalline limestone.	4.0
Limestone, solid, blue, fine grained; conchoidal fracture; apparently very pure; calcite sheets at top, at base, and in middle.	2.6
Shale, calcareous; light gray and yellow on weathered surface, dark and fresh fracture.	6.5
Limestone, solid but impure; dark gray and fine grained on fresh fracture, but very light gray and yellow on weathered surfaces; calcite seam at top with a slickensided surface.	3.0
Shale, calcareous, very platy and papery; weathers yellowish and light gray; contains a number of solid but impure limestone layers (2 to 6 inches thick); shaly parts show much diagonal "shear" parting.	7.5
Shale, calcareous, light gray, with diagonal "shear" parting.	.5
Limestone, massive, somewhat nodular, impure, dark gray, with several crystalline, fossiliferous seams.	3.9
Limestone, single layer, finely crystalline, light bluish; conchoidal fracture; calcite seam at top.	.3
Limestone, massive, somewhat nodular, impure, dark gray, with several crystalline fossiliferous seams.	4.0
Limestone, single layer, finely crystalline, light bluish; conchoidal fracture; 1/2 inch calcite seam at top.	.4
Limestone, massive, dark gray, crystalline, not distinctly nodular; fossils show on weathered surface sparingly. ..	2.2
Limestone, massive, nodular, impure, dark gray, coarsely crystalline layers; calcite seams persistent parallel to bedding.	8.1
Limestone, massive, nodular, impure, medium gray; nodules pure, matrix impure and shaly. *Favosites,* in large heads, abundant in lower 7 feet.	12.8
Limestone, massive, nodular, impure, much like unit above; calcite seams, ...	12.3
Limestone, massive, nodular, dark gray, impure; 1/2-inch seam of calcite at base; when weathered looks thin bedded.	5.8
Limestone, massive, nodular, dark gray; conchoidal fracture.	5.5
	139.8
Tonoloway limestone:	
Limestone, dark gray, pure, crystalline; solid bed; shows a rude columnar character in places; has everywhere one or two 1/2-inch calcite seams at base.	3.2
Limestone, thin bedded (1 to 3 inches); beds do not seem to separate, and unit looks rather massive; dark gray fine grained, conchoidal in part; crystalline in part; very pure.	20.4

Tonoloway limestone—continued.	Thickness in feet.
Limestone, thin bedded (3 to 6 inches), dark gray, in part coarsely crystalline.	1.7
Limestone, massive, dark gray, crystalline.	4.7
Limestone, impure-looking, dark gray, banded; much very fine, disseminated pyrite; purer than the next lower unit.	2.5
Limestone, impure, gritty-looking, dark gray, with a pronounced diagonal parting; looks as if it had been sheared.	3.6
Limestone, massive, banded, pure, dark gray; shows columnar structure.	2.4
Limestone, shaly, dirty gray; irregular, diagonal "shear" parting; 1 inch of calcite at base.	.6
Limestone, massive, banded, pure, gray; shows columnar structure in places.	4.7
Limestone, alternating shaly and pure in 1-inch courses	.9
Limestone, massive, dark gray, pure, banded.	.8
Limestone, same, not banded.	.6
Limestone, massive, dark gray, pure, banded	1.7
Limestone, dirty gray, sandy-looking but contains no sand; shows everywhere an irregular diagonal parting as if it had been sheared	.7
Limestone, pure, platy, dark gray.	1.0
Limestone, very massive, blue-gray; shows no banding.	3.2
Limestone, pure, very platy, laminated; has some geodal calcite layers; shows distinct rude columnar structure in places.	6.9
Limestone, pure, dark gray, fine grained; conchoidal fracture.	1.0
Limestone, pure, dark gray, very platy and laminated	1.0
Limestone, light gray, fine grained; conchoidal fracture; has black layers which mottle its fracture surfaces.	.8
Limestone, platy, dark, impure, passing into weathered yellow calcareous shale above.	3.2
Limestone, pure, thin bedded (3 to 6 inches), blue-gray.	1.0
Shale, calcareous, weathered, yellow with some geodal calcite layers and several thin limestone streaks.	6.7
Limestone, fairly pure, but thin bedded and platy.	6.2
Limestone, impure, banded, platy, light gray; curly layer near base contains small radiating masses of strontianite.	2.2
Shale, weathered, yellow.	.6
Limestone, curly, dull gray, fine grained, with much disseminated pyrite	.2
Limestone, heavy, blue-gray, pure, fine grained; shows some banding.	3.0
Limestone, impure, shaly-looking; weathers into thin laminae; perhaps a little purer in middle 3 feet.	12.0
Limestone, pure, dark gray, thin bedded (1 to 2 inches)	.9
Limestone, impure, shaly, dark gray.	1.5
Limestone, fairly pure, dark gray, thin bedded (1 to 2 inches).	2.5
	102.4

Stone Crusher area.

The Susquehanna Stone Company, trading under the name of the Williamsport Stone Company, has a large quarry at Stone Crusher, on the east bank of Susquehanna River about half a mile north of the Dauphin-Northumberland line. The Oriskany formation which borders the railroad has been cut through and the underlying Helderberg exposed.

The blue-black limestone forming the base of the quarry is slaty and is probably Tonoloway. It is regarded as a slate by the men and is not worked. The thickness could not be estimated because of the covering of debris. The sequence above the blue-black limestone is: a thin limestone, a thin layer of calcite, a 41-inch bed which is badly shattered, a harder gray limestone 25 feet thick composed of beds that average from two to eight inches in thickness. These beds die out to the east. Over them is another bed which may be distinguished by means of large nodular pieces of limestone, some of which are more than a foot in diameter. Below them the rock changes and much calcite vein material appears.

The quarry is worked in benches to which the men gain access by ropes and from which the large stones are thrown to the quarry floor thus breaking them up.

MONTOUR COUNTY.

The Helderberg limestones crop out in two narrow east-west bands a short distance north of the Susquehanna River and in a loop in the vicinity of Washingtonville.

Washingtonville area.

The main quarries in this area are about two miles southwest of the town of Washingtonville. They are all along Limestone Ridge. No detailed reports of these quarries are available because they were not working at the time of the visit.

The largest quarry is the one operated by Alex Billmeyer. It is situated along the north side of Limestone Ridge formed by the southern flank of the Milton major axis. Here the limestone beds are from one to three inches thick and are quite shaly. These thin beds are overlain by a somewhat shaly and sandy soil approximately four feet deep. Below this sandy and shaly limestone the more massive limestones occur, and here the thickness of the individual beds averages six inches. The total thickness of the massive limestones is about 35 feet. The strike of the formation is N. 75° E. and the dip is 18° SE.

Five kilns on the property show signs of having been used only as the farming community demanded lime. Practically all the limestone extracted from the quarries in this area is burned.

The Umpstead quarry is directly opposite the Billmeyer working and is in practically the same beds. It is not as large and supplies three small kilns.

The Coleman quarry is in a narrow valley due east of the other operations, and supplies two kilns. This quarry has been in operation for only a few years but the opening of the others dates back to 1866. In the quarry the rock seems to be quite thin and flaggy and is dark in color. It is most likely the Toroloway member. This dark limestone, overlain by a more massive blue rock, is hard and has a few fossils on the weathered surfaces. Some limy shales near the base of the quarry seem to grade into the pale, green shales of Salina age.

In the Bright quarry, the lowest member is also the Tonoloway and it is about 30 feet thick. It is in direct contact with the so-called "Bastard" limestone.

About half a mile north of Washingtonville along the road to Strawberry Ridge, there are several abandoned quarries. These belonged to Messrs. Moser and Schultz and were abandoned on account of flooding. They had been worked steadily until 1910 when an underground stream was struck. Flooded conditions rendered a detailed investigation impossible.

Grovania area.

Near the eastern line of the county along the southern band of limestone which lies east of Danville in Montour County is the old Grove quarry, now operated by Alonzo Mauser. The operator had leased a portion of the quarry to the Winton Construction Company which was building a part of the State road through the section. This company was concerned chiefly with the "Bastard" limestone of White, which makes a highly suitable road material.

Mauser quarry.—The basal beds of this quarry worked by Alonzo Mauser for burning lime represent the dark, slaty Tonoloway. Some of the beds are bluish gray and others are black with numerous calcite veins giving them a "layer-cake" appearance. The rock breaks with ease and has a slaty fracture which is similar to slaty cleavage. Most of the beds are about half an inch thick and are exposed for a total thickness of 6½ feet. They grade upward into a blue-gray limestone which is capped by a thin streak of calcite. The overlying 12 feet consists of a grayer and more massive limestone. These beds are separated from the overlying "Bastard" limestone, which is about 25 feet thick, by another shaly member. The "Bastard" limestone comes to the base of the quarry to the east, and here it is worked by the Winton Company.

Above it are numerous ledges of differently colored limestones ranging in thickness from four to six feet and dotted with abundant clay seams and pockets. There is also much transverse calcite veining and the fossils are scarce.

About 125 feet of limestone are exposed in the entire quarry which produces approximately 125 tons of crushed stone per day. Mr. Mauser burns approximately 650 bushels of lime each week. Steam drilling and hand sledging are the methods of quarrying and the stone is hauled up a steep incline to the crusher. The face of the quarry is 1400 feet long and the floor is about 30 feet wide. The Winton Company is operating in an area of about 10,000 square feet.

Section at Grovania.[40]

	Thickness in feet.
Limestones and shales of undetermined age, but probably New Scotland and Oriskany	110
Helderberg limestone:	
Coeymans limestone member:	
Sandstone, coarse (grains 1/16 to 1/8 inch in diameter), white; base filled with crinoid stems and other fossils; contains some chert	3.0
Keyser limestone member:	
Limestone, irregular, crinoidal, dark blue	1.6
Limestone, compact, light, blue, heavy bedded; conchoidal fracture	5.5
Limestone, laminated, light gray to yellowish, platy. Has some solid 6-inch layers of light-gray rock, but for the most part is rather shaly. Barren of fossils	36.4
Limestone; a peculiar pebbly stromatoporoid makes up whole of rock	3.0
Limestone, blue, pure, with many transverse calcite seams; massive and somewhat nodular; composed almost entirely of stromatoporoids; has 1/2-inch layer of shale at top	3.4
Shale, yellow	.2
Limestone, composed almost entirely of stromatoporoids	5.6
Shale, blue-black, with one or two limestone layers	4.6
Limestone, crystalline, blue, pure,	1.3
Limestone, crystalline, blue, pure, many transverse calcite seams	.8
Limestone, crystalline, blue, pure, massive; weathers thin bedded; has much black shale. Stromatoporoids throughout	8.0
Limestone, crystalline, blue, pure, massive; numerous transverse thin calcite seams; weathers thin bedded	10.0
Limestone, heavy bedded, light gray; has great masses of vein calcite	6.0
Limestone, crinoidal, relatively impure	.6
Limestone, light gray, nodular; much shalier than the beds beneath; weathers easily; "Bastard" limestone of the quarrymen	23.6
Shale, irregular	.3
Limestone, irregularly bedded, somewhat nodular, dark gray; courses often separated by shale laminae	11.6
	122.5

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[40] Reeside, op. cit., pp. 224-225

Tonoloway limestone:

Limestone, dark gray, pure; conchoidal fracture; many transverse calcite seams; when unweathered is a massive unit though 1-inch bedding is shown in the upper part and 6-inch bedding near the base; it is not nodular or platy; shows a persistent thin shaly layer	12.0
Limestone, fissile, platy, dark gray; joints have yellow discolored borders	10.0
Limestone, fissile, platy, much weathered	6.0
Limestone, solid, dark gray, banded in parts	6.6
Limestone, fissile, platy, much weathered, yellow; fresh surface is dark gray	4.3
Concealed.	38.9

Mausdale area.

The Mausdale area in Valley township has but one working quarry that of D. J. Crossley, which is in the east side of the same ridge as the abandoned quarries of Maus and Bright.

After removing a small quantity of overburden, a pure limestone was uncovered. The beds are about two inches thick and make up a total of about six feet. Under this thin material a massive blue gray limestone occurs, full of calcite veins. There are also many clay seams which average about three inches thick and seem to be regularly alternated with the limestone. The grayish blue limestone is by far the best quarry rock in the locality. It has very little apparent variation in quality and structure. The clay seams often terminate in a shaly and slaty formation which is splintery and fragile. This quarry is owned by William McMahon, and was formerly operated by Charles Cook. It has produced 1200 to 1400 bushels of lime per week under the Crossley management.

The Russell quarry is across the ridge, and was formerly operated by the Philadelphia and Reading Coal and Iron Company to supply their Danville furnaces. Here the chief formation is the Tonoloway which is about 70 feet thick. The chief bed, although inaccessible for close study, showed the platy appearance of the Tonoloway and was directly beneath the Stromatopora bed of the Keyser. The "Bastard" limestone overlies the Stromatopora bed, and in this quarry is approximately 20 feet thick. The strike of the rocks here is practically the east-west strike noticed in many quarries. The dip is 35° S. The quarry was operated along the line of strike. The material was used chiefly for lime.

Other localities visited in Montour County included the Strickler quarry in the southeastern part of Liberty township. This quarry is partially in the Tonoloway formation, as can be easily recognized by the thin and flaggy aspect of the beds and the overlying massive Stromatopora bed of the Keyser.

COLUMBIA COUNTY.

The outcrop of Helderberg limestones in Columbia County is in the form of a long loop like a hairpin that extends from Montour County to Berwick. The two arms are approximately parallel to each other and to the course of the Susquehanna River and are about three miles apart.

These limestones have been quarried extensively, especially in the vicinity of Rupert, Espy, Almedia, and Lime Ridge. Within two miles of the western border of the county there are four large quarries. The Summer quarry was the only one in operation during the summer of 1921.

About 70 feet of Tonoloway limestone are exposed on the west side of Eck quarry. It varies from a bluish-gray pure limestone to a somewhat impure rock. It becomes shaly and exhibits the typical blue-black flaggy aspect of the Tonoloway and is underlain by a harder grayer rock. The same succession is seen in the other quarries in this vicinity and also five miles east in Lime Ridge where a larger quarry face in Lowe Brothers' quarry made a detailed examination possible.

The chief operators in the Ridge which stretches from Bloomsburg through Espy to Almedia are Lowe Brothers, Herbert Huffman, Mr. Hess and Mr. Wooley.

A person entering the Lowe quarry from the east sees the flaggy, blue limestone, which weathers to a bluish gray. It is abundantly fossiliferous. This limestone forms the uppermost member of the ridge which is now being rapidly worked away. It is undoubtedly the Keyser member and is the old Stormville of White. The black shaly limestone of Tonoloway age is referred to by the quarrymen as "black stone."

Beneath the blue limestone which forms the top of the Ridge, a thin, hard, sandy ledge six feet thick makes its appearance. This ledge is underlain by a very hard, impure gnarly limestone. Because this gnarly limestone breaks out in rudely rectangular blocks it is used as slabs for paving. The "Bastard" limestone which occurs beneath it, has been quarried and sold as a building stone.

The Stromatopora bed is visable in the Wooley quarry which is directly east of the Lowe quarry. It is thinly laminated and shows occasional sandy streaks. Because of the abundance of calcitic material scattered throughout the limestone it has been referred to by the quarrymen as "bird's eye" limestone.

Lowe Brothers' quarry.—The upper beds of the quarry are shaly, gray, fossiliferous limestones, ranging in thickness from half an inch to several inches. They are underlain by a black shaly bed which resembles the "black stone." The black bed is about 15 feet thick and is underlain in order by a somewhat sandy layer 8 feet thick, a gnarly bed 6 feet thick, the "Bastard" limestone, and the black flaggy Tonoloway which is here represented by three distinct lithologic units.

The quarry runs in an east-west direction along the outcrop and is about a quarter of a mile long. It is worked in bench fashion. The total output is about 1400 bushels of burned lime per day. There are 11 kilns. Most of the lime is sold to the Paragon Plaster Company which operates on an adjacent lot.

Hess quarry, Almedia.—The upper three feet of this quarry which is high on the ridge is thin, shaly, roughly laminated beds. Beneath them is a one-foot bed of bluish limestone with numerous calcite veins and a six-inch ledge of shale below. Under the shale, the "Bastard" limestone shows for 15 feet and is the chief quarry rock.

The quarry is some distance from the railway. The crushed material is hauled down the hillside in carts to the kiln.

Herbert Huffman quarry.—The rock in the Huffman quarry northeast of Espy is rather massively bedded, hard, and somewhat siliceous. The entire thickness of limestone that is exposed is 40 feet. The beds average from three inches to two feet in thickness. Where pure vein calcite is found it is usually accompanied by sizable lumps of sphalerite and galena and the operator claims to have found some native copper. An old adit leading to the galena and sphalerite workings was in poor condition and did not permit an examination of the rocks below the surface.

The hard and massive limestone is overlain by a bed of shaly and crumbly limestone about six feet thick, in which the individual layers average four to six inches. This crumbly limestone carries many fossils, and is somewhat shaly near the base where a shelly limestone appears. Much overburden prevents the working of the lower portions of the quarry. These appear to be the best lime beds in the county.

LYCOMING COUNTY.

The Helderberg formation crops out in an almost east-west direction through the county, in the Susquehanna Valley from Jersey Shore to within two miles of Muncy and is approximately two miles wide. The belt includes the large quarries at Hughesville. Here the belt swings southwestward and crosses the Susquehanna at Muncy. It has a southwestward trend to Elimsport and at that town makes a sharp turn to the east. It is on this backward swing that it passes through the White Deer Valley, and Gregg township, Union County.

Five areas in this county visited and described are Jersey Shore, Montoursville, Hughesville, Williamsport, and White Deer.

Jersey Shore area

There are three quarries in the Jersey Shore locality and one of these was working. The working quarry of this area was owned by the Jones estate and operated by Henry Carpenter. It is located about one mile northwest of the borough along Pine Creek.

Borough quarry. The Jersey Shore Borough quarry is being worked intermittently and in it both flanks of a syncline can be seen. It is about a quarter of a mile east of the trolley bridge over Pine Creek. The northern flank of the syncline so well exposed in this quarry dips 15° SE. and the southern limb 50° NW. Along the axis there has been considerable shattering and the material is not good for road use. The upper layers are shaly, weather to a buff yellow, and are brittle. The lower beds are massive and contain some chert. Few fossils were found and the lithological character, together with the finding of chert, indicates that the formation is of Keyser age.

Henry Carpenter quarry. This quarry one mile northwest of Jersey Shore along Pine Creek was working on a road contract and intermittently burning lime. The rocks exhibit a true Helderbergian aspect and are quite uniform throughout. The lowest rocks visible in the quarry are dark blue, and carry many calcite veins and some rhombs of calcite. Cubes of fluorite were also found. The "Bastard" limestone is above the dark blue limestone and is quite hard. It is light gray and is exposed for a thickness of 50 feet. The individual beds average about eight inches thick.

Numerous *spirifers* and *leptaena* were found, and one large pelecypod, which was poorly preserved.

Siebering quarry. This quarry is a short distance west of the borough quarry, and shows a much faulted face. It has been abandoned for the last 17 years. Much chert is found in the eastern end, and from all appearances the rocks are of the Keyser formation. Some fluorite was also found.

Montoursville area.

On the north side of the road between Williamsport and Montoursville several quarries have been opened to obtain stone for roads, for lime, and for building purposes.

Bower Brothers quarry, midway between Williamsport and Montoursville, has been worked intermittently for more than 40 years. The quarry is about 400 feet long and 100 feet wide with a face about 20 feet high. The strata dip to the north at angles of 10° to 15°. Some shaly stone present that is not suitable for lime, is used for walls and rough construction. The good stone is mottled, strikingly so when weathered. Two kilns are in operation. The product is called the Blue Stone Lump Lime and used for agricultural purposes and for plastering. Many cracks and solution pockets filled with clay and occasional alluvial boulders up to two feet in diameter have been encountered in the quarry.

Nearer Montoursville there are two adjoining quarries in the Helderberg limestone. One of them belongs to Loyalsock Township and is worked for road metal. The strata dip 5°-10° N. except in the northeast corner of the quarry where they are almost vertical and are badly shattered. The other quarry is operated by the West Branch Lime Co. The beds dip 5°-20°N. in the major part of the quarry. The east end of the quarry shows the axis of an anticline with beds dipping south. The quarry is about 300 feet long, 75 to 100 feet wide, and the working face up to 45 feet high. Several shaly layers are interbedded with the more massive although laminated rock. Fossils and sun cracks are common in the more shaly layers. The stone is burned in two kilns for agricultural and building lime.

Hughesville area.

Near Hughesville the formations are rather uniform and the description that follows is a generalized one. The quarry of A. T. Armstrong is representative of the area and it alone will be described.

A. T. Armstrong quarry. The lower or basal member of the quarry is a hard, black limestone, known locally as "firestone". It is used as a flagging stone. Some of the slabs are four inches thick. The slabby limestone is 15 feet thick and is overlain by a dark blue massive bed 20 feet thick and made up of individual layers averaging ten to twelve inches. The stone from the quarry is used mainly for road metal. At the time of the survey A. T. Armstrong was supplying material for the State road from Sunbury to Muncy.

Overlying the bed of massive blue limestone is a bed of indefinite thickness which has been used for burning in the four neighboring quarries. It has occasional streaks of calcite veins and is termed "niggerhead". Another dark limestone, 20 feet thick, appears above it and is made up of individual beds averaging six inches in thickness. This is the best lime burning rock in the ridge. A more siliceous, fossiliferous rock above it is termed the "hardcap" layer.

The dip in the quarry is 15°NE. and the strike N 20°W. The rocks of the quarry average 77 per cent $CaCO_3$ and 2.75 per cent $MgCO_3$.

West of the Armstrong working is the Bull-Artley quarry which has three kilns. This quarry was not in operation during the summer of 1921, but it showed the same beds that were being worked in the Armstrong quarry. Next to it is the McConnell quarry also in the same formation. Farther west is the Reeder quarry with a battery of 25 kilns. It is by far the largest operation visited in the study of the Helderberg. The Kigler quarry adjoins the Reeder operation.

Reeder quarry. The M. E. Reeder quarry differs slightly from the Armstrong in that it is being driven in on a lower level and shows a denser and more massive limestone ranging in color from gray to dark blue. It is capped by a hard, siliceous layer. A more or less shaly material forms the upper layer of the quarry. Some large calcite veins are visible. One of these measured a foot in thickness. The rocks dip 25° NE.

White Deer Valley area

The area is bounded on the south and west by White Deer Ridge and on the north by Bald Eagle Mountain. The belt of Helderberg limestone crops out in a curve through Montgomery, Maple Hill, and Elimsport and then eastward paralleling White Deer Ridge.

The only quarries seen in this area are in the vicinity of Elimsport and are operated by J. P. Baker and J. P. Best. In both these quarries the beds being worked are hard, dark blue limestones, with a few calcite veins running through the massive beds. The beds are about 20 feet thick and are made up of layers two to five feet thick.

Directly over the massive bed is a softer lighter blue limestone which is rather siliceous and breaks with a glassy fracture. This is, in turn, overlain by a shaly limestone which is never burned for lime. The beds average about three feet thick and make a total of 20 feet. There is much evidence of cave material in both quarries.

Analyses of Helderberg limestones of Lycoming County[41]

	1	2
$CaCO_3$	60.964	70.589
$MgCO_3$	30.691	1.740
SiO_2	6.960	21.680
Al_2O_3 Fe_2O_3	1.330	4.660
S	.100	.027
P	.003	Trace

No. 1. One half mile north of Jersey Shore.
No. 2. Ferguson quarry, 2 miles west of Jersey Shore and 1 mile above mouth of Pine Creek.

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[41] Pennsylvania Second Geol. Survey, Rept. M3, p. 94, 1881.

CLINTON COUNTY.

The Helderberg limestones of Clinton County form a band from one to two miles wide extending entirely across the county but they are exposed in few places. The Susquehanna River flows through the belt from Lock Haven eastward and Bald Eagle Creek flows through the limestone belt from the Centre County line to its junction with the Susquehanna below Lock Haven. Both of these streams have formed wide flood plains of alluvial deposits that conceal the underlying rock. It is improbable that these limestones will ever be of much value in this section.

CENTRE COUNTY.

The Helderberg limestones outcrop in a narrow band extending entirely across Centre County in the Bald Eagle Valley. Throughout most of the county they are concealed by alluvial debris deposited by Bald Eagle Creek and talus that has rolled down from Bald Eagle Mountain. The limestone has been quarried in only a few places.

On either side of Unionville, near Milesburg, and about two miles south of Eagleville the Helderberg has been quarried for roads and to make agricultural lime. In the old quarry at Milesburg about 30 feet of limestone is exposed dipping 30° N. It is shaly and seems to be impure. A sample analyzed by the Cambria Steel Co. showed 2.36 per cent SiO_2. Between Milesburg and Howard there are few exposures and nothing seen that appears promising.

On account of the excellent limestone of Cambro-Ordovician age in the Nittany Valley on the other side of Bald Eagle Mountain it is improbable that there will ever be any extensive use of the Helderberg limestone of Centre County.

HUNTINGDON COUNTY.

The outcrop of the Helderberg limestones loops back and forth across Huntingdon County in six narrow bands that extend nearly or quite across the county in a northeast-southwest direction. Almost everywhere the limestone helps to form narrow deep valleys bordered by high ridges of resistant sandstones.

Reeside[42] has given the following detailed section near Mapleton.

Section in Swope quarry, near Mapleton.

	Thickness. in feet.
Helderberg limestone (Keyser limestone member):	
Concealed by talus, quarry waste, etc. Much of the talus of the upper part is ash-colored shale.	
Limestone, light gray; banded on weathered surfaces; fresh surface dark gray, fine grained, not banded; conchoidal fracture; 3-inch courses separated by shale	9.0

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[42] Reeside, op. cit., pp. 209-211.

	Thickness, in feet.
Limestone, like unit above but not in courses separated by shale; fairly massive	4.8
Shale, calcareous, weathered, yellow	.9
Limestone, very light gray, compact, fine grained; dark on fresh surface; faintly banded	2.8
Limestone, composed entirely of *stromatoporoids*	.9
Shale, weathered yellow	.8
Limestone, massive, light gray; composed of *stromatoporoids*	3.0
Limestone nodules, large, in shale matrix	.8
Limestone, rather platy, shaly dark gray	4.3
Limestone, dark gray, conchoidal, impure, fine grained; in 2 to 12 inch courses, separated generally by thin shale laminae	19.1
Shale, calcareous, containing large nodules (diameter 5-6 inches) of limestone and one or two beds of fine-grained conchoidal blue limestone	4.3
Limestone, rather shaly, dark gray; single bed	1.6
Limestone, massive, impure, gray; nodular character indistinct; weathers thin bedded at top of quarry	3.1
Limestone, massive, impure, nodular	1.3
Shale, weathered, yellow	.5
Limestone, impure, nodular, dark gray, somewhat crystalline	3.4
Limestone, impure, dark gray; many cleavage faces of calcite show, giving it a coarse grain; very massive unit; shows indistinct nodular structure	5.6
Limestone, much like unit above but does not show the nodular structure	8.8
Limestone, dark, much weathered in places, massive	3.9
Limestone, pure bluish crystalline layers alternating with shaly dark-gray impure layers; the whole makes a massive unit. Bryozoa throughout	5.0
Limestone, light gray, fine grained, conchoidal fracture	2.0
Limestone, massive, coarsely crystalline, bluish; many small chert nodules	2.4
Limestone, blue gray, coarse, crystalline, pure, thin bedded (2 to 6 inches)	1.1
Limestone, shaly, impure, "Bastard"; weathers light gray and yellow; finely nodular	9.6
Limestone, bluish gray, crystalline, single bed, fairly pure	2.8
Limestone, very impure, earthy, dark gray; shaly fracture	1.5
Shale, fissile, calcareous; weathers a ferruginous brown; has some nodules near top	1.0
Limestone, impure, nodular, dark, single bed	2.0
Limestone, fairly pure, blue, crystalline; nodular character lacking on fresh surfaces and very indistinct on weathered surfaces; thin bedded (2 to 4 inches); a few 2-inch chert nodules scattered near top	5.6

	Thickness in feet.
Limestone, nodular, relatively impure, rather coarse grained and with considerable interlaminated shale; would be classed as a "Bastard" limestone, but it is purer than the unit beneath	2.4
Limestone, shaly, very nodular, "Bastard", light gray and brown on weathered surfaces	3.5
Limestone, coarsely crystalline, light gray, very pure (98 per cent $CaCO_3$), extremely massive and crinoidal	29.8
Limestone, thin bedded (2 to 3 inches), dark gray, fine grained, distinctly nodular	1.7
Limestone, somewhat nodular but yet massive, dark gray, fine grained	3.8
	153.1
Tonoloway limestone:	
Limestone, medium bedded (4 to 12 inches), pure, dark gray, not banded; shale between the courses	6.8
Limestone, thin bedded (3 to 6 inches), pure, dark gray, fine grained; banded and light gray on weathered surfaces	2.8
Shale, calcareous	.2
Limestone, massive, dark gray, fine grained, pure; conchoidal fracture; in places shows a 1-inch bedding	3.8
Limestone, light gray, in 3-inch courses with shale between	1.8
Limestone, massive bed, very light gray, fine grained; conchoidal fracture. In this unit there has been dissolved out a good-sized cave reaching down to an unknown depth. The limestone seems very pure and has small scattered masses of crystalline calcite	4.0
Limestone, banded, thin bedded (2 inches) but not fissile, light gray, pure	5.5
Travertine	.5
Limestone, banded, thin bedded, light gray	3.6
Limestone, very platy, fissile; weathered surfaces have a faint greenish tinge	2.6
Limestone, rather irregular, heavy bed, fine grained, light gray, pure	1.2
Limestone, very platy, fissile, light gray, fine grained; seems fairly pure	3.4
Limestone, dark gray, with a 4-inch layer of chert at center	1.3
Limestone, massive, finely (1-inch) but distinctly nodular, dark gray, impure. Corals	3.0
Limestone, massive, fairly pure, blue gray	3.6
Limestone, fissile, platy, dark gray; layer of chert	5.2
Limestone, fairly solid, banded, dark gray, fine grained	8.9
Limestone, fissile, shaly, impure; drab on fresh surface	5.6
Limestone, fairly pure, knotty, light gray, fine grained	1.5
Limestone, fissile, weathered, brown and gray, fine grained, impure	12.4
Concealed	5.9

	Thickness in feet.
Shale, weathered, calcareous, gray to brown	7.4
Shale, poorly exposed, weathered	4.0
Limestone, fissile, impure, gray	5.5
Limestone, platy, gray; looks much purer than unit above or below	1.0
Limestone, fissile, impure, weathered brown	1.0
Concealed	3.8
Limestone, thin bedded (4 to 6 inches), impure light gray	5.0
Shale, calcareous, gray, and limestone, gray to brown weathered, fine grained: alternating layers of each about 3 inches thick	9.4
Shale, fissile, ash-colored, calcareous	5.5
	126.2

As in other districts these limestones have been quarried mainly for agricultural lime although plastering lime, stone for ballast and for flux have been obtained in many places.

In Hopewell Township near the Bedford County line the Helderberg limestones were formerly quarried for flux for a blast furnace one mile to the east. There were 30 to 40 feet of good limestone in the quarry. White [42] gives the following section and analyses of specimens in a quarry near Grafton.

Section in Helderberg limestone quarry near Grafton.

		Feet
1.	Top layers of gray crystalline limestone	10
2.	Blue limestone	10
3.	Cherty ("nigger head") limestone	2
4.	Ironstone	4
5.	Gray limestone	5
6.	Blackish limestone	7

Analyses of samples from various layers in limestone quarry near Grafton.

	Upper part of 1	Lower part of 1	4	5	6
$CaCO_3$	95.536	98.035	94.642	95.446	93.035
$MgCO_3$	1.589	.908	2.800	1.135	1.816
SiO_2	1.851	.420	1.730	2.350	3.480
Al_2O_3 and Fe_2O_3	.490	.410	.370	.520	.730
P	.011	.011	.006	.006	.006

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[42] White, I. C., The geology of Huntingdon County: Pennsylvania Second Geol. Survey. Rept. T3, pp. 125-126, 1885.

Near McConnellstown the Helderberg limestones have long been quarried for lime[13]. East of Petersburg along the Juniata River these limestones have been extensively quarried and have furnished much stone for ballast and some that has been used as flux in iron furnaces.

In the vicinity of Mapleton there has been extensive quarrying of the Helderberg limestones. The material has been burned for agricultural lime and used for roads. It contains on an average about 9 per cent SiO_2.

In a quarry near Mt. Union the Helderberg limestone has furnished stone for lime. In the upper part of the quarry good stone is interbedded with cherty layers. The lower part of the quarry contains 43 feet of massive dark-colored tough limestone. Seven samples from this layer averaged 3.4 per cent SiO_2.

Southeast of Shirleysburg some good stone is exposed but it is interbedded with cherty layers. In an old quarry between Orbisonia and Black Log Mountain where lime was formerly burned there is an exposure of cherty limestone.

BLAIR COUNTY.

The Helderberg limestones are well developed in Blair County and have been extensively worked in several places. The band of outcropping strata extends in a southwesterly direction through Tyrone and the eastern part of Altoona to a short distance beyond Duncansville where it makes a broad loop passing through Hollidaysburg and near Frankstown to a point a few miles north of Canoe Creek. It then turns to the southwest and follows along the west flank of Lock, Loop, Short, and Dunning mountains to the Bedford County line passing through Flowing Spring, Reservoir, and McKee Gap.

The Helderberg (including the Tonoloway) limestones within the county are more than 400 feet thick. There is a great variation in the character of the material as indicated by the following detailed section by Reeside[14]

Section at Lincoln and Fifteenth Streets, Tyrone

	Thickness. in feet.
Concealed: scattered outcrops of dark gray and brown fissile shale: a few bands of impure limestone.	
Helderberg limestone:	
New Scotland limestone member:	
Limestone, medium bedded (1 foot), fine grained, light gray: contains chert lentils and shale laminae	4.4

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[13] Op. cit., p. 200.
[14] Reeside, op. cit., pp. 205-206.

	Thickness in feet.
Shale, weathers brown	1.4
Limestone, impure, fine grained, thin bedded, light gray, in courses 8 inches thick, with shale partings	2.6
Limestone, shaly, weathered	.8
Limestone, massive, heavy bedded, coarse grained, crystalline, gray; much interbedded chert	4.8
	14.0
Coeymans limestone member:	
Limestone, very impure, shaly, yellowish	3.8
Limestone, somewhat weathered, light gray, coarsely crystalline; Line of chert nodules (2 by 10 inches) near the top	2.0
Limestone, massive, coarsely crystalline, dark	2.5
	8.3
Keyser limestone member:	
Limestone, single bed, light gray, fine grained, impure	1.1
Limestone, very shaly, light gray	1.8
Limestone, light gray, fine grained, platy	.8
Shale, brown, weathered	2.9
Limestone, light gray, fine grained, platy	1.1
Shale, brown, weathered	2.0
Limestone, impure, brownish gray, very platy; breaks into sheets half an inch thick	4.6
Limestone, pure, fine grained, brownish gray; in two beds separated by brown shale; has conchoidal fracture	2.7
Limestone, shaly, banded, dark gray; contains carbonaceous films	1.5
Limestone, composed entirely of stromatoporoids	2.3
Limestone, shaly, yellowish gray. Scattered heads of stromatoporoids	2.0
Limestone, composed entirely of stromatoporoids; under surface very irregular	3.2
Shale, brown, weathered	.4
Limestone, composed entirely of stromatoporoids and corals; under surface irregular	5.9
Limestone, buff, fine grained, shaly	1.5
Limestone, extremely massive, composed entirely of corals, Bryozoa, and stromatoporoids	9.4
Limestone, with profusion of corals and stromatoporoids	6.0
Shale	.6
Limestone, coarsely crystalline, gray	1.0
Limestone, coarsely crystalline, gray. Scattered stromatoporoids	3.0
Limestone, coarsely crystalline, gray	3.5
Limestone, massive, coarsely crystalline	7.7
Limestone, thin bedded (1 to 6 inches), crystalline, light gray	3.5

	Thickness in feet.
Limestone, massive, coarse grained, light gray	5.0
Limestone, thin bedded, gray, and shale	1.5
Limestone, brownish gray to buff, in single bed standing out as a ridge; coarse, crinoidal	3.9
Limestone, thin bedded, coarse, gray	.6
Shale	.4
Limestone, buff, massive, coarse grained, crystalline	3.6
Limestone, brownish gray, single bed. Fragments of fossils on surface	2.5
Limestone, thin bedded, buff; drab on fresh fracture	2.3
	88.3

Tonoloway limestone:

Limestone, massive, buff	2.0
Limestone, massive, fine grained, buff, cherty	1.4
Limestone, massive, fine grained, buff, banded	6.4
Limestone, fissile, banded, buff; drab on fresh fracture	11.7
Shale, buff, calcareous, contorted and in places apparently brecciated	7.8
Shale, weathered, brown, earthy	1.0
Limestone, massive, fine grained; weathered surface light gray, fresh fracture drab; banded; contains some thin chert lentils	6.7
Limestone, platy, banded, fine grained, light gray	2.3
Limestone, platy, laminated, fine grained, buff	.9
Limestone, buff to light brown, platy; much geodal calcite in small crystals	1.3
Limestone, fissile, light gray	2.3
Concealed; probably platy limestone	4.0
Limestone, light gray, platy, impure	1.0
Limestone, light gray in solid bed; platy fracture	3.3
Limestone, platy, fine grained, buff	4.0
Concealed; brown shale in part	15.0
Limestone, platy, buff	2.5
Shale, calcareous, and fine siliceous oolite (?); weathered surface ferruginous, brown; bedding irregular	2.4
Limestone, blocky, fine grained, buff	1.3
Shale, weathered brown	2.5
Limestone, platy, fine grained, buff	2.3
Shale, calcareous, much weathered; some fine-grained sandy (?) layers (siliceous oolite?) stand out	10.3
Shale, calcareous, buff to light gray	1.5
Limestone, fairly pure, fine grained, buff, blocky fracture	4.0
Limestone, buff, platy, laminated in part	6.3
Limestone, shaly, platy, yellowish; many geodal calcite masses with large fine crystals	5.0
	109.2

The Helderberg limestones in the region have been quarried in many places for lime flux, and crushed stone for concrete and highway construction. For agricultural lime, crushed stone, and ordinary flux a large portion of the rocks can be used although even for these purposes some of the shaly beds must be discarded. Near the base of the Keyser formation there is a persistent bed of extremely pure massive limestone that has been quarried for chemical lime and high grade flux. It is best developed in the Frankstown region where it averages about 25 feet in thickness and is known as "calico rock." It is a compact bluish gray containing numerous small "eyes" of white calcite which in the weathered rock are stained a dull red.

Altoona.—In the east and southeast part of Altoona the Helderberg limestones have been worked for lime in the past but in recent years the demand for crushed stone has increased so that all material now quarried is sold for concrete and highway purposes. The principal operating quarry is that of Bell and Bockle on the hill just east of the city. The layer of pure limestone mentioned above is present but where exposed contains numerous caves and clay pockets. On the east side of the creek north of the fair grounds there are several exposures and plans have been formed for opening a quarry there. A quarry has been opened in these strata near Canaan.

Hollidaysburg.—The American Lime and Stone Co. has operated in two localities near Hollidaysburg. The first place is about 1 1/2 miles northwest of the city where the layer of pure limestone was worked for chemical lime. There are 3 kilns near the quarry. At the time of our visit the quarry was being operated by a leasing company that was taking out the impure underlying rock for highway use. A stratum containing great heads of corals of the *Stromatopora* type overlies the pure limestone. The other locality is near the top of the hill about midway between Hollidaysburg and Frankstown where openings extend in a line for almost a mile. The stratum of "calico" limestone about 25 feet thick has been extensively quarried (See Plate XII, A) for the manufacture of chemical lime and the underlying and overlying impure beds for crushed stone.

Section exposed in Frankstown quarries

	Feet
Impure thin bedded granular limestone	20
Shaly limestone disintegrating to a clay containing calcareous fossiliferous nodules	3
Pure massive limestones ("calico" rock)	25
Impure thin-bedded limestone	?

PLATE XII.

A. Quarry in Helderberg limestone, Frankstown, Blair County.

B. Greenbrier limestone, Thompson quarry, 6½ miles east of Uniontown, Fayette County.

The strata dip at about 35°SE. The pure limestone is especially sought but as it dips beneath the impure layers, it can only be quarried economically when there is sale for the overlying impure material as crushed stone. The granular limestone would make a fair grade agricultural lime were it not for the fact that it breaks up into a powder in the kilns. The lime made from the good stone is sold as lump lime and is used mainly in the manufacture of paper. The following analyses of this lime were made in the laboratories of the Williamsburg Mill of the West Virginia Pulp and Paper Co. between Dec. 1918 and Mar. 1919. Each represents an average shipment of 10 cars of lime.

Analyses of lime made at Frankstown quarries.

CaO ----	92.52	93.53	94.23	91.91	90.60	89.59	91.20	93.12	93.22	91.41
MgO (by difference)	1.47	1.14	1.25	1.10	1.51	.60	2.68	1.22	1.31	1.22
SiO_2 ----	3.96	3.12	2.44	4.04	3.56	7.42	3.98	2.84	3.02	3.30
Al_2O_3 Fe^2O_3 -	1.44	1.60	1.46	2.20	1.72	1.80	1.80	1.24	1.64	1.92
Loss on ignition	.61	.61	.62	.75	2.61	.59	.34	1.58	.81	2.15

Half a mile south of Duncansville, there is a quarry operated by the Duncansville Lime and Stone Co. The "calico" stratum, about 25 feet thick, is burned for agricultural lime and the overlying less pure beds crushed for road metal. The beds are considerably folded and are displaced by a fault that passes through the quarry. The overlying strata are a 3-foot bed of impure nodular limestone and above that granular gray stone of fair quality.

Canoe Creek.—About 1 1/2 miles northwest of Canoe Creek Station are the operations of the Canoe Creek Stone Co. The Jones and Laughlin Steel Co. formerly worked a quarry at this place for flux. At the time of our visit the company was working the impure beds both below and above the pure ("calico") stone for road metal and planned to save the good stone for high grade flux or the manufacture of chemical lime. The strata are similar to those of the Frankstown quarries.

The same beds have been worked by the Calcium Products Co. about 2 miles north of Canoe Creek Station where they are making chemical lime from the layer of "calico rock" that at that point is about 30 feet thick. An average of 3 samples analyzed by the Cambria Steel Co. gave the following results: $CaCO_3$ 95.00, $MgCO_3$ 2.25, SiO_2 1.25, S. .04, P. .004.

Several similar analyses of the high grade limestone formerly used for flux by the local iron furnaces are given in the Report on Blair County (T) of the Second Geological Survey of Pennsylvania (pp. 129 and 130).

BEDFORD COUNTY.*

The Helderberg limestones are exposed in two narrow bands that extend entirely across the county from northeast to southwest and two other bands that form a loop about six miles north of Bedford and extend from Bedford southward as two separate but parallel bands. In addition there are a few other smaller areas.

The Helderberg limestones have been most extensively quarried for the manufacture of agricultural lime for local consumption and perhaps scores of small quarries have been opened throughout the county. When the iron ores of the region were mined a number of iron furnaces obtained much of their flux from the Helderberg limestones. In recent years these limestones have furnished much stone for highway construction and some quarries still are worked to supply small lime kilns.

The largest operation in the Helderberg limestone in Bedford County is that of the Enterprise Lime & Ballast Co. at Hyndman. The following description is from a report made to the company by Messrs. A. H. Jones and F. S. Deekens, Jr., Cumberland, Maryland. March 13, 1923.

The Enterprise Lime & Ballast Company is situated at Hyndman, Pennsylvania, between the Connellsville Division of the Baltimore & Ohio Railroad and the Juniata Division of the Pennsylvania Railroad. The plant manufactures crushed limestone for railroad ballast and for highway and building purposes, as well as lime for commercial and agricultural use.

The lime plant consists of a battery of four Shoop kilns, twelve feet in diameter and thirty feet high, with facilities for grinding the lime into a fine powder and mechanically packing it for shipment.

The crushing plant consists of two Champion crushers (No. 3 and No. 5) with rotary screens forty inches in diameter and fifteen feet long.

These plants and the buildings housing them were erected in the years 1912 and 1913 and have been in almost continual operation, seasonally, since that date. From time to time, new buildings have been erected and additional machinery installed to take care of the increase in production.

The quarry contains massive seams of limestone, the strata of which have been tipped to an angle of nearly ninety degrees with the horizontal. These seams have been divided, in this report, into three classes:

1. Limestones suitable for calcination.

   The lower (Manlius) part is a fine-grained blue stone which burns into a good agricultural lime. The upper portion is the "Gray Fossil" (Helderberg), a coarse-grained stone which makes a superior grade lime, suitable for commercial purposes as well as agricultural. This bed has a thickness of about 220 feet.

2. Limestones suitable for crushing.

   This member has a thickness of about 180 feet. Dark blue, flinty limestones prevail, with thin beds of shaly stone. The formation is mainly Helderberg and extends into the Oriskany.

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*By R. W. Stone.

3. Calcareous sandstone suitable for crushing.
   This member is of the Oriskany formation but is essentially a low grade limestone in its lower third. It is a dense, hard stone, crushing clean, and has been used extensively for State road work in both Pennsylvania and Maryland. One hundred feet of this seam is considered marketable and is being quarried.

At the present working face, the quarry is about 400 feet wide and 80 feet high. As the quarry progresses, it becomes continually higher until, near the extreme boundary of the property, it will reach a height of nearly 280 feet.

Analyses of limestone from quarry of Enterprise Lime & Ballast Co., Hyndman, Pa.

[Fleming Testing Laboratory, Analyst.]

	1	2	3
Silica	7.000	2.150	7.800
Alumina	2.170	.750	2.550
Calcium carbonate	81.650	93.697	87.830
Magnesium carbonate	8.556	2.928	1.500
Phosphorus	.011	.008	.009
Sulphur	.090	.040	.050
Ferric oxide	.430	.300	.200
	99.907	99.873	99.939

1. Blue limestone 40 feet thick, west of high-grade gray fossiliferous limestone.
2. Gray fossiliferous limestone.
3. Fine-grained blue limestone east of No. 2.

On Irvin Burket's land at Hyndman two stone draw kilns attract attention to a quarry that is concealed by trees and a wall of rock. Two narrow cuts through shaly, cherty limestone lead to a quarry 100 feet long, 30 feet wide, and up to 40 feet deep in the center. The beds are vertical, the walls sheer, and the strike N. 40° E. This property was last operated about 1922.

In 1924 Mike Burket burned lime ⅛ mile south of Hyndman. The two stone draw kilns are supplied from a new quarry which has been driven 60 feet on vertical beds 30 feet wide. The face of the quarry is about 35 feet high and increases as the quarry advances between the vertical walls. The stone is a deep bluish black, massive, knotty limestone. Parallel with this quarry and separated from it by a wall of lower grade limestone is an abandoned quarry several hundred feet long, narrow, and between vertical walls closely resembling a railroad cut.

In Cumberland Valley township limestone has been quarried in a small way on several farms and burned for agricultural lime. In 1924 the only quarry in this township operated commercially was that on the farm of Amos Miller one mile east of Centerville (Cumberland Valley P. O.). It was leased and operated by A. C. Valentine. The quarry face, which is 40 feet long and 20 feet high, shows an upper knotty bed, a middle bed of massive limestone, and a shaly bottom bed, all of blue-black limestone. The beds dip west at a low angle. The rock is burned in a single draw kiln. Other quarries in this township are those of J. D. Cessno and Peter Hite, near Centerville, and James McFarran, Burning Bush.

At Manns Choice two quarries on the same massive black limestone ledge are operating side by side in the north end of the village. The New Baltimore Lime Co. operates one and Dave Hillegas the other. The beds strike N. 30° E. and dip W. 80°. At each quarry the rock is burned in a draw kiln, the lime is pulverized in a 12-inch jaw crusher and sold for agricultural use.

At Napier, on the Lincoln Highway, 5 miles west of Bedford, the State Highway Department is quarrying the Helderberg limestone on the George Sauser farm. The beds strike N. 40° E., and dip W. 60°. The quarry has been driven 200 feet along the strike on 50 feet of blue-black limestone that is thin-bedded near the surface but massive at the quarry floor. The walls on either side are yellow, shaly limestone not fit for highway use. The face in 1924 was about 70 feet high.

Half a mile south of Everett, A. M. McClure is quarrying a blue, massive, knotty limestone and burning it in two draw kilns. In 1924 he was working a new face about 30 feet high and wide. The original source of rock for these kilns was a quarry opened by driving a tunnel through the steeply dipping beds to a higher grade limestone. In the south end of the old open quarry a cavern has been opened about 80 feet long, 25 feet wide, and 30 feet high, apparently enlarging a natural cavern. The beds at this place strike N. 35° E. and dip E. 50°.

Just west of Everett there is a quarry in the Helderberg limestone that is said to have been worked to supply local kilns for the last 100 years. The strata used are about 50 feet thick, including a 4-foot bed of very pure stone, the "calico rock" of the Frankstown, Blair County, section. The remainder of the section used was less pure but it produced a fair grade of agricultural lime. At the time of our inspection the quarry was being worked entirely for road material and a much greater thickness was being quarried. It is mainly a nodular gnarly blue limestone.

Stevenson[45] in his report mentions many places throughout the county where the Helderberg was formerly quarried for lime and flux but most of these quarries have long since been abandoned. In the table of analyses that follows most of the materials reported by Stevenson obviously came from the purer strata that make up only a small portion of the entire Helderberg series.

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[45] Stevenson, J. J.: The geology of Bedford and Fulton counties: Pennsylvania Second Geol. Survey, Rept. T2, 1882.

Analyses of Helderberg limestone in Bedford County.

	1	2a	2b	2c	2d	3	4
$CaCO_3$	98.178	96.61	85.81	94.28	91.95	89.635	92.875
$MgCO_3$	1.854	1.44	2.82	3.27	1.86	1.876	1.891
SiO_2	.230	1.28	7.56	1.54	4.24	6.880	4.810
$\left.\begin{matrix}Al_2O_3\\Fe_2O_3\end{matrix}\right\}$	.114	.34	3.22	.64	2.50	.610	.370
S	.020	.06	.32	.04	.07	.022	.060
P	.007	.010	.010	.009	.011	.005	.005

	5	6	7	8a	8b	9	10	11
$CaCO_3$	96.592	94.107	90.660	82.60 to 92.90	87.19	91.071	84.500	96.592
$MgCO_3$	2.459	2.444	2.542	1.27 to 10.40	5.19	2.543	10.019	2.459
SiO_2	.930	2.750	6.250	2.60 to 7.06	4.62	5.590	4.820	.930
$\left.\begin{matrix}Al_2O_3\\Fe_2O_3\end{matrix}\right\}$	.240	.240	.822	1.20 to 3.90	2.45	.440	.713	.240
S	.019	.036	.056	.04 to .30	.11	.068	.062	.019
P	.008	.010	.008	.006 to .032	.013	.006	.012	.008

1. W. Devore's quarry south of Hyndman (T2 p. 97), 2a, 2b, 2e and 2d. Enterprise Lime and Ballast Co., quarry, Hyndman. Analyses by Cambria Steel Co.
3. Wilmetto Limestone Co. quarry just north of Wills Creek Station. (T 2, p. 106).
4. Shoemaker quarry immediately north of Manns Choice. (T 2, p. 112).
5. A. Stuckey's quarry, Napier Township (T 2, p. 115).
6. L. Geisler's quarry, a short distance east of St. Clairsville (T 2, p. 129).
7. Hull's quarry, King Township (T 2, p. 132.)
8. R. N. Oppenheimer farm, 6 miles north of Bedford. 5 samples, 8a, range, 8b average.
9. Stapleton's quarry, ½ mile south of Juniata River, southwest of Everett (T2, p. 191).
10. J. Piper's quarry, on Piper's Run, Hopewell Township (T2, p. 196). Analyses by Cambria Steel Co.
11. Kemble Coal and Iron Co's quarry near Cove Station, Black Valley, within a few rods of the Huntingdon County line. (T2, p. 200).

FULTON COUNTY.*

The Helderberg limestone occurs mainly in Dublin and Bethel townships in the northern and southern parts of Fulton County. In the vicinity of Fort Littleton the limestone has been quarried for local use on several farms. Half a mile north of Fort Littleton on the Stevens farm, shallow excavations have been made for several hundred feet along the outcrop of a black limestone. The beds are thin, ranging up to one foot thick, strike N. 10° E., and dip west 30° into the hill. At a depth of 10 feet or less, sinking down the dip is stopped by the difficulty of getting the rock up over the lip of the quarry. One or two men work here intermittently and burn the rock in a draw kiln.

On the John S. Wollett farm 2 miles southwest of Fort Littleton a quarry face 200 feet long and up to 30 feet high exposes a massive-bedded, dark blue, mottled, and fossiliferous limestone. The beds strike N. 30° E. and dip W. 30°. Vertical joints are conspicuous and calcite veinlets are common. This quarry and its draw kiln, which are hidden in the woods, have not been worked for several years.

About 500 feet south of the Wollett quarry are several small excavations in limestone on the John Martz farm. Here the bedding is nearly vertical and the high grade deep blue rock is separated by bands of impure shelly limestone several feet thick. Limestone was quarried here until 1921 and burned in open heaps for agricultural lime. Similar small excavations have been made on nearby farms for the same purpose.

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*By R. W. Stone.

In the southern part of Fulton County the Helderberg limestone has been quarried in a small way and burned for agricultural lime on many farms. Among these are the Oliver Hill, Moses Hess, Job Hess, Frank Fisher, and Henry Garland farms south of Nevermore.

Two miles north of Warfordsburg, G. Edward Golden is quarrying the Helderberg limestone beside the State highway and burning it in two draw kilns. The beds strike N. 20° E. and dip W. 70°. The quarry follows the strike for 75 feet, making a cut 40 feet wide between sheer walls 35 feet high. The limestone is black, massive, and contains gash veins of calcite. A similar quarry on the same beds east of the road has been abandoned. Mr. Golden crushes the lump quick lime and sells it for land dressing.

At Warfordsburg 2 miles north of the Maryland line a quarry was opened many years ago for stone to build the house now owned by W. B. Rank. The aqueducts on the canal at Hancock, Maryland, also were built of limestone from this quarry. In recent years rock was taken from this quarry to build the State road through Warfordsburg, and a face has been developed that is 100 feet long, and 18 feet high in the middle. At present the quarry is worked only occasionally by Mr. Rank for stone that is hauled to farms within a radius of 10 miles and burned in open heaps for agricultural lime.

Analyses of Helderberg limestones of Fulton County.

	1	2	3
$CaCO_3$	93.117	87.357	91.303
$MgCO_3$	2.043	2.346	2.043
SiO_2	4.110	8.430	5.550
Al_2O_3 } Fe_2O_3 }	.600	1.930	.810
S	.075	.020	.201
P	.006	.002	.004

1. Fisher quarry, Bethel Township (T2, p. 274.)
2. Johnston quarry near Licking Creek, Thompson Township, about 2 miles from the Maryland State line. (T2, p. 291.)
3. Ramsay quarry, one-third mile north of Fort Littleton (T2, p. 304.)

CHAPTER VI.

SILURIAN AND DEVONIAN LIMESTONES EXCLUSIVE OF THE HELDERBERG AND TONOLOWAY.

The Silurian and Devonian formations of the State, outcropping in many places in a broad belt, extending from Wayne County in a southwesterly direction to Bedford County, contain numerous calcareous members other than the important Helderberg (including the Tonoloway) limestones. They are contained within the Clinton and Salina formations of the Silurian and the Oriskany, Onondaga (Corniferous), Marcellus, Hamilton, Chemung, and Catskill formations of the Devonian. Everywhere they are of minor economic importance and, in the field investigations for this report, little attention was given to them due to lack of time and to their relatively small value. The short descriptions that follow are taken mainly from various reports of the Second Geological Survey of Pennsylvania.

POTTER, TIOGA, AND BRADFORD COUNTIES.

As in other regions, the Chemung and Catskill formations of Potter, Tioga, and Bradford counties contain occasional beds of impure limestone that in the absence of better grade material have been quarried for agricultural lime and for flux.

Numerous thin beds of impure limestones in the upper 100 feet of the Chemung formation have been quarried on a small scale in many places for agricultural lime and at one time were quarried near Mansfield for use as a flux in a local iron furnace. About a mile east of Burlington, Bradford County, about 40 feet of fossiliferous limestone, termed the Burlington limestone, has been quarried for agricultural lime.

Analyses of Chemung limestones.[46]

	1	2
Sesqui-oxide of iron	4.428	2.142
Alumina	2.613	2.269
Lime	41.048	28.872
Magnesia	1.135	1.117
Sulphuric acid	.167	.087
Phosphoric acid	.279	.729
Carbonic acid	33.240	23.227
Insoluble residue	18.010	41.700

1. Kline quarry, 1 mile east of Burlington, Bradford Co.
2. G. R. Wilson quarry, near Mansfield, Tioga Co.

The Catskill formation contains some calcareous strata in a few restricted localities. They do not seem to be of any economic importance.

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[46] Pennsylvania Second Geol. Survey Rept. G, pp. 38, 62. (1878).

SUSQUEHANNA AND WAYNE COUNTIES.

The only limestones of Susquehanna and Wayne counties are extremely impure and of little value. In the vicinity of Great Bend, Susquehanna County, a layer of impure limestone is interbedded with the Chemung shales and sandstones. It is not continuous and where developed varies from 6 inches to 2 feet in thickness.

The principal limestone of these counties is in the Catskill formation. It is known as the Cherry Ridge limestone although it scarcely deserves the name of a limestone as shown by the analyses given below. It is developed over a large part of Wayne County and the eastern tier of townships in Susquehanna County. By careful selection some rock has been obtained that was fairly satisfactory for farm lime. In Vol. G5, (p. 65) of the Second Geological Survey of Pennsylvania the following analyses are given:

Analyses of Cherry Ridge limestone.[47]

	1	2	3	4
SiO_2	28.800	65.470	75.220	80.950
$CaCO_3$	64.392	19.785	17.696	11.196
$MgCO_3$	1.816	3.518	1.589	1.664
Al_2O_3 Fe_2O_3	4.145	8.903	4.432	4.988
P	0.050	0.095	0.034	0.030

1 and 2, Schenck quarry, Cherry Ridge Township, Wayne County. 1, best stone; 2, poorest stone.
3 and 4. J. Multen's land, Oregon Township, Wayne County.

LYCOMING AND SULLIVAN COUNTIES.

In a number of places in Lycoming and Sullivan counties there are calcareous strata within the Catskill sandstones. So far as known the only place these limestones have been worked is about half a mile north of Millview, Sullivan County. Three limestone strata separated by considerable intervals of shales and sandstones are said to be developed in that region, the lowest of which was quarried for agricultural lime. The section exposed in the quarry as described by Platt[48] is as follows:

Section in quarry at Millview, Sullivan County.

	Ft.	in.
Small limestone layer, blue	2	0
Red sandstone	8	0
Limestone	2	6
Slate	2	6
Limestone	3	0

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[47] Pennsylvania Second Geo. Survey, Rept. G 5, p. 65, 1881.

[48] Platt, F., Pennsylvania Second Geol. Survey Rept. GG, p. 222, 1880.

Analyses of the limestones in Millview quarry.

	1	2
$CaCO_3$	80.393	69.000
$MgCO_3$	5.653	5.387
$MnCO_3$	3.116	1.689
S	.240	.092
P	.133	.144
Al_2O_3 Fe_2O_3	5.196	5.870
Insoluble residue	5.240	17.850

1. Upper layer.
2. Lower layer.

WYOMING, LACKAWANNA, LUZERNE, COLUMBIA, MONTOUR AND NORTHUMBERLAND COUNTIES.

Impure limestones have been noted in a number of places in the Clinton; Salina, Hamilton, and Marcellus formations of these counties through which the North Branch of Susquehanna River flows. In no place are they thick, pure, or continuous over large areas. Although quarried locally to a small extent, they are of very little value.

The lowest limestones are in the Clinton formation. This formation contains occasional thin fossiliferous limestones, especially in the vicinity of Danville, Montour County. They are seldom more than 1 foot thick. The beds of fossil iron ore formerly worked near Danville and Bloomsburg have been observed to pass into impure limestones containing 70 per cent of calcium and magnesium carbonates.

The Salina formation contains a number of impure limestones interbedded with shales. They are more or less magnesian and generally have a light green or buff tint. At an old quarry about 1 mile from the southern boundary of Valley Township, Montour County, and near the west branch of Mahoning Creek one of these beds is about 20 feet thick and some fluxing stone was formerly obtained for the Danville furnaces. In general they are decidedly shaly and entirely too impure to be of much value, even too impure for good agricultural lime. They are more abundant in the Upper Salina although there are occasional limestones developed in the Middle Salina.

Near the top of the Hamilton formation a series of gray, shaly, impure limestones aggregating 50 feet in thickness is present in some localities. They probably represent the Tully limestone. They possess little or no economic value.

Near Selinsgrove Junction there is a series of interbedded shale and light gray limestones in the lower part of the Marcellus with a total thickness of 65 feet. Although the limestone is generally impure, a few beds are sufficiently pure to have been quarried for agricultural lime.

MONROE AND CARBON COUNTIES.

The only limestones of the Silurian and Devonian systems, exclusive of the Helderberg, of Monroe and Carbon counties are the Corniferous and Tully limestones. The former is of some economic importance but the latter is only of scientific interest.

The Corniferous (Upper Helderberg, Onondaga) limestone is well exposed in Monroe County and appears in a few places in Carbon County. It crops out in Monroe County from Delaware River near the mouth of Big Bushkill Creek westward at the base of the northern slope of Walpack Ridge to Stroudsburg where it disappears either through gradation into a sandstone or by the cover of glacial debris or both. It is not seen again until within a short distance of the Lehigh River above Lehigh Gap.

In Monroe County the width of the outcrop of the Corniferous strata is seldom more than one-fourth mile and generally less. The beds are about 200 feet thick near Stroudsburg and about 25 feet thick near Lehigh Gap.

White[49] gives the following descriptions of the Corniferous limestone. The Corniferous beds "consist of successive layers of dark gray limestone 1′-10′ thick, in which are embedded multitudes of black flint nodules one inch to one foot in diameter, having no regular shape but usually longer than thick, the greatest axis lying parallel with the bedding planes. On exposed surfaces the lime has been removed by solution while the nearly insoluble chert stands out in numerous black projections 6″-8″ high, giving the beds a most forbidding aspect, the sharp dagger-like points being the terror of bathers. No portion of the rock seems to be free from these flint nodules and in some parts of the stratum they make up nearly half of its material. They are not wholly silicous, but often contain a considerable quantity of lime, and then the nodules break up and decay by atmospheric influences; the lime being removed by solution leaves the silicious material in such a rotten or spongy condition that it also succumbs to the elements.

"The origin of these nodules by segregation is attested by the fact that they are often seen enclosing fossil shells, crinoids, etc.

"The following analysis by McCreath and Stinson shows the composition of an average specimen of these cherty nodules; locality, East Stroudsburg, Monroe County:

Carbonate of Lime	20.267	99.148
Carbonate of Magnesia	0.681	
Oxide of Iron and Alumina	0.640	
Insoluble residue	77.560	
The ignited "insoluble residue" gave		
Silica	72.430	73.605
Oxide of Iron and Alumina	0.770	
Lime	0.210	
Magnesia	0.195	

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[49] White, I. C., The Geology of Pike and Monroe counties: Pennsylvania Second Geol. Survey, Rept. G 6, pp. 117, 118, 120, 1882.

"Of course there are many of the nodules that do not contain so much lime as this specimen, while others contain much more, if one may judge from the readiness with which they decompose when exposed to atmospheric influences.

"The limestone part or matrix which holds the flint nodules has the following composition as determined by McCreath and Stinson:

I. From East Stroudsburg, Monroe County.

II. From land of H. H. Campbell, Smithfield, Monroe County.

	I	II
Carbonate of Lime	89.014	83.750
Carbonate of Magnesia	0.915	1.157
Oxide of Iron and Alumina	0.380	0.480
Sulphur	0.056	0.025
Phosphorus	0.012	0.070
Insoluble residue	9.860	14.470
Total	100.237	99.952

"It has been burned for lime on several farms in Monroe county; but owing to the fact that the flint nodules were not separated from the matrix or pure limestone, the experiments in this direction have been far from satisfactory, since a very large amount of material always failed to slack, or else melted down into a silicious slag. The analyses given on a preceding page show the matrix of these nodules to be a very fair limestone for agricultural purposes, and one which should slack with no difficulty. If the farmers, when breaking the stone into small fragments for the kiln, would cast aside the flinty nodules, there would be no trouble in manufacturing large quantities of it into an excellent fertilizer and it would pay them to do this rather than haul their lime 5 or 10 miles further from the No. VI beds (as nearly all of them do,) even if half of the Corniferous rock should be rejected in freeing it from the flint.

"Then too, some of the beds are much more cherty than others, the topmost layers usually containing more of the flint nodules than any other portion of the series; so that by a judicious selection of the quarry and proper care in casting aside the flint nodules, the farmers of eastern Monroe ought to make this the main source of the lime they use for agricultural purposes, at a great saving in cost compared with the price of the Lower Helderberg lime (No. VI) when hauled a distance of 5 miles or more."

The Corniferous limestone near Palmerton in Carbon County consists of 5 feet of limestone containing flint nodules and 20 feet of soft underlying argillaceous limestone that was at one time burned for hydraulic cement. It is said that all the masonry of the Lehigh Canal was laid with cement made from this limestone.

Near the top of the Hamilton formation there is a layer of shaly limestone or calcareous shale that seems to represent the Tully limestone. It is mainly a great mass of corals embedded in a shale matrix. It is about 30 feet thick and probably in no place sufficiently rich in calcareous material to be of value as a limestone.

BLAIR AND CENTRE COUNTIES.

In Blair and Centre counties some calcareous strata within or just below the Marcellus shales in a few places pass into true limestones, although generally they are more properly termed calcareous shales. In Bald Eagle Valley there are a few occurrences of this character, notably about 2 miles southwest of Unionville. On Juniata River in Blair County there are also some dark blue to gray argillaceous limestones, alternating with green, olive and gray calcareous shales, at about the same horizon. So far as known, they have not been quarried.

UNION, SNYDER, MIFFLIN, JUNIATA, AND PERRY COUNTIES.

In the counties of Central Pennsylvania west of Susquehanna River there are many local limestones in the Clinton, Salina, and Marcellus formations.

The Clinton formation contains many thin limestones, but, as far as known, in no place are they sufficiently thick to be quarried. They pass into fossil iron ore that formerly was mined in many places.

In the Upper Salina there are greenish-colored magnesian limestones and calcareous shales that may possibly be pure enough to be worked for agricultural lime in certain localities although in general they are far too impure to be of any economic importance.

Near the base of the Marcellus there is a series of variable limestones of rather wide distribution in these counties. Along Juniata River east of Newton Hamilton the series is about 40 feet thick, consisting of hard gray siliceous limestone in beds 2 to 4 feet thick. It has been quarried for lime. The same limestone series occurs in the Tuscarora Valley, especially at Peru Mills where there is a 2-foot bed of good limestone underlain by impure greenish limestones and calcareous shales. In Perry County, particularly in Madison Township, the Marcellus limestone series, aggregating 50 feet in thickness, contains some beds of hard limestone suitable for agricultural lime. They are interbedded with thin seams of dark shale.

HUNTINGDON, BEDFORD, FULTON, AND FRANKLIN COUNTIES.

In Huntingdon, Bedford, Fulton, and Franklin counties there are occasional thin limestone lenses within the Clinton, Salina (Cayugan), Oriskany, Marcellus, and Hamilton formations but economically they are of little importance.

White[50] describes from the Clinton formation of Huntingdon County, "thin beds of light gray, bluish-gray limestone, streaked with calcite, slightly fossiliferous (with some greenish-gray shale partings,) quarried for flux for Barree furnace, although not of the best quality, as shown by three analyses: A, specimen from the upper part of the 10′ quarry bed; B, from the lower part; C, average specimen."

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[50] White, I. C., The geology of Huntingdon County: Pennsylvania Second Geol. Survey Rept. T3, pp. 132-133, 1885.

	A	B	C
$CaCO_3$	96.000	91.000	89.911
$MgCO_3$			2.028
$Al_2O_3+Fe_2O_3$			1.790
SiO_2			5.660
P	Trace	Trace	0.014
S	0.750	0.190	

Butts[51] describes 275 feet of shale and limestone overlying the Clinton formation of Blair and Huntingdon counties as the McKenzie limestone. It is probably the same member that is present as thin-bedded limestones in Little Cove, Franklin County. Similar limestone beds are developed in Red or Rocky Ridge, Bedford County. In Pennsylvania they are of little importance but near Hancock, Md., have been used in the manufacture of Portland cement.

Butts also describes the lower part of the Oriskany as the Shriver limestone. It is a thin-bedded siliceous limestone 200 feet thick.

The lower part of the Marcellus (possibly representing the Onondaga) contains many limestone beds. Northeast of Saxton, Bedford County, Stevenson[52] observed the following sections.

Section of Marcellus beds at Saxton, Bedford County.

	Ft.	In.
Shales black, wrinkled like gneiss or micaceous shale, breaking like rotten wood	12	0
Limestone, blue	0	5
Shale, like No. 1	0	2
Limestone	0	3
Shale	0	6
Limestone	0	3
Shale	1	0
Limestone	0	2
Shale, wrinkled like No. 1	3	0
Limestone	0	3
Shale, wrinkled like No. 1	1	0
Limestone, upper surface wrinkled	0	3
Shale	5	0
Limestone	0	5
Shale	4	0
Limestone	0	4
Shale	12	0
Limestone	0	6

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[51] Butts, Charles, Geologic section of Blair and Huntingdon counties, Central Pennsylvania: Amer. Jour. Sci., 4th ser., vol. 46, pp. 523-537, 1918.

[52] Pennsylvania Second Geol. Survey, Rept. T2, pp. 83-84, 1882.

Shale	1	3
Limestone	1	0
Shale	10	0
Limestone	0	5
Shale	7	0
Limestone	0	4
Shale	8	0
	68	5*

"Below this the limestone is less in quantity. It is present at all localities."

White[53] describes these same limestones in Huntingdon County as follows:

"The Marcellus limestone and lower shales make a low but distinct terrace all along the bottom slope of Warrior's ridge. Thin beds of greenish-gray or bluish-green limestone, with but few fossil shells as a rule, are enclosed in beds of black slate and dark shale, without any of those chert nodules which occur at this horizon in New York State and along the Delaware river in Monroe and Pike counties.

"Moreover, what fossils there are belong to Hamilton rather than to Corniferous types. It is better, therefore, to regard these beds as the lowest group of the Marcellus sub-division of the Hamilton formation, resting immediately upon the Oriskany.

"They are well exposed on the gentle slope of Warrior's ridge just north of the Car Works in West Huntingdon, and fairly well in the bluff opposite Huntingdon (just south of the middle Penitentiary building) along the public road, thus:

Bottom beds of Marcellus black slate	——
Bluish-gray impure limestones and limy shales	12′
Black slates	40′
Bluish-gray and greenish-gray limestones	10′
Dark shales (and concealed beds.)	20′
Oriskany sandstone	——

"The interval is here 82′ but may be said to average 75′, and the limestone layers at other exposures occur at various places in the interval."

Near the top of the Hamilton formation in Huntingdon County there is a calcareous stratum from 1 to 5 feet thick that seems to be the Tully limestone. It is of little value.

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*This section adds to 69 feet 6 inches, 13 inches more than as printed in the original report. Editor.

[53] Pennsylvania Second Geol. Survey, Rept., T3, pp. 114-115, 1885.

CHAPTER VII.

CARBONIFEROUS LIMESTONES.

Geographic and Stratigraphic Position.

The Carboniferous rocks appear at the surface over more than one-half of the State. They are the only, or practically the only, outcropping rocks in Allegheny, Armstrong, Butler, Cambria, Clarion, Clearfield, Fayette, Greene, Indiana, Jefferson, Lawrence, Mercer, Venango, Washington and Westmoreland counties and are well developed in the following additional 30 counties: Blair, Bradford, Cameron, Carbon, Centre, Clinton, Columbia, Crawford, Dauphin, Elk, Erie, Forest, Fulton, Huntingdon, Luzerne, Lycoming, McKean, Monroe, Northumberland, Perry, Pike, Potter, Schuylkill, Somerset, Sullivan, Susquehanna, Tioga, Warren, Wayne, and Wyoming.

The Carboniferous System is subdivided into periods and formations as follows:

- Permian.
  - Dunkard series (Upper Barren Measures)
    - Greene group
    - Washington group

- Pennsylvanian
  - Pittsburgh series
    - Monongahela group (Upper Productive Measures)
    - Conemaugh group (Lower Barren Measures)
    - Allegheny group (Lower Productive Measures)
  - Pottsville series (Conglomerate)

- Mississippian
  - Mauch Chunk series
  - Waverly series
    - Pocono group

With the exception of the anthracite coal regions, where all of the strata above the Pottsville conglomerate are grouped under the name "Coal Measures," the above classification is followed throughout the State, although the thinning and changing character of the Pocono, Mauch Chunk, and Pottsville, proceeding westward from the anthracite regions, renders exact correlations somewhat uncertain in some places.

In addition, each of the formations has been subdivided into members that have been given more or less local names. The common practice is to name certain beds that either are of economic importance or are fairly persistent and uniform so that they serve as good horizon markers. Thus almost every coal or limestone bed has received a specific name. Many of the limestones that are of little or no commercial value are of considerable use for correlation purposes as they are apt to be more persistent than the coals, sandstones, or shales and various coals are identified by their position with reference to particular limestones. In the county descriptions that follow, many limestones are mentioned even though they are insignificant.

Limestones have been quarried from each one of the formations or groups listed although they may be thin, non-persistent, and of inferior quality. The best and most abundant limestones are developed in the Allegheny, Monongahela, and Washington groups. The Allegheny assumes first rank because of the Vanport limestone, the most valuable limestone of the Carboniferous strata of the State.

Character and Use.

The Carboniferous limestones of Pennsylvania represent both marine and fresh water deposition. In some cases it is somewhat uncertain as to whether they are marine or fresh water deposits. The marine limestones contain many fossils, as a general rule, whereas the fresh-water beds are deficient in organic remains although careful search is apt to reveal the presence of occasional minute shells.

The fresh-water limestones resemble each other much more than the marine ones. They are almost invariably bluish-gray to a dove-colored gray or slightly yellow and weather to a chalky white. They are compact and have a tendency to break with a prominent conchoidal fracture. They are so soft that rarely do they fulfill the rigid specifications for road metal, and in addition are, in the main, high in argillaceous content. They are generally low in magnesium carbonate. They are also extremely variable, frequently undergoing extreme changes in thickness, physical characteristics, and chemical composition within a few miles.

In contrast, the marine limestones of the Carboniferous present more variations in their physical and chemical composition but individual beds maintain their diagnostic features over much wider areas. The Vanport, Ames, and Greenbrier, all of marine origin, can be recognized by their physical characteristics alone over wide areas whereas additional data are generally required in the case of the fresh water beds.

The Carboniferous limestones of the State have been most widely used for agricultural lime, most of which has been made in small kilns for local use. Much lime has also been made by heap roasting. Formerly fluxing limestone was obtained in many places but at present only stone of good quality is desired for blast furnace use and the Vanport limestone of the Allegheny group is the only satisfactory one. The same limestone is the only one that is being utilized for the manufacture of Portland cement although it is possible that some others might be of some value for this purpose. A similar statement might be made concerning the uses of the Carboniferous limestones for road metal, chemical lime, and for construction purposes. Locally, however, it has been found advisable to use poor grade stone in preference to stone of better quality that would have to be shipped in.

Unlike the older limestones of the State, the Carboniferous limestones are almost exclusively confined to regions where the folding action has been slight. They therefore are flat-lying or with gentle dips. Most of them outcrop along the sides of the steep-sided valleys that so largely prevail in the western part of the State. This facilitates the opening of small hillside quarries at the outcrop but presents great difficulty in the development of large quarrying operations unless the stratum sought caps the hill or lies so near the top that the overburden of shale and sandstone is thin. Where the limestone is sufficiently valuable to justify underground mining it is an easy matter to follow in the hill from the outcrop. The valuable Vanport limestone is being mined in several places and in at least one locality the upper Freeport has also been mined.

The Carboniferous limestones of the State are most numerous in the southwestern portion and become less abundant and, in general, of less economic importance as one proceeds northward and northeastward. For example the Carboniferous limestones of the two northern tiers of counties as well as those of the entire anthracite region are negligible while about a dozen of the counties in the southwestern portion of the State contain fairly abundant limestone.

In the county descriptions that follow it has seemed best to start with those regions where the limestones are most abundant and proceed toward the northeast. They are taken up in the following order:

1. Greene.
2. Washington.
3. Fayette.
   Westmoreland.
4. Somerset.
5. Bedford.
   Fulton.
   Huntingdon.
6. Beaver.
   Allegheny.
7. Lawrence.
   Mercer.
   Venango.
   Butler.
8. Armstrong.
   Clarion.
9. Indiana.
   Cambria.
10. Jefferson.
    Clearfield.
11. Blair.
    Centre.
12. Crawford.
    Erie.
13. Forest.
    Elk.
    Cameron.
14. Warren.
    McKean.
15. Potter.
    Clinton.
    Lycoming.
    Tioga.
    Bradford.
    Sullivan.
16. Anthracite coal regions.

GREENE COUNTY.

A number of limestones have been recognized throughout Greene County although most of them are locally developed and do not extend through the entire county. Many of them have been worked to supply stone for agricultural lime and several have furnished material for the roads. For the latter purpose much of the stone is condemned as it has a tendency to disintegrate rapidly when exposed to the weather. Some of these limestones have been accepted by the State Highway Department in the construction of water bound macadam roads but rejected for concrete roads.

Practically all of Greene County has been mapped since 1900 by the U. S. Geological Survey and the results published in Geologic Folios Nos. 82, 121, 146. Most of the data contained in this section is abstracted from these folios with minor changes. Bulletins Nos. 65 and 249 of the U. S. Geological Survey and Report K of the Second Geological Survey of Pennsylvania contain much valuable information, especially several local sections. There is considerable lack of agreement in these various publications which cannot be discussed here. The generalized section given below is compiled from these sources.

Generalized geologic section of Greene County.

Carboniferous	Feet
Permian (Dunkard series)	
Greene group	750±
Windy Gap limestone	
Windy Gap coal	
Gilmore sandstone	
Nineveh sandstone	
Nineveh coal	
Nineveh limestone	
Hostetter coal	
Fish Creek sandstone	
Dunkard coal	
Tenmile coal	
Washington group	400±
Upper Washington limestone	
Jollytown limestone	
Jollytown coal	
Middle Washington limestone	
Blacksville limestone	
Lower Washington limestone	
Washington coal	
Little Washington coal	
Waynesburg "B" coal	
Calvin (Colvin's) Run limestone	
Waynesburg "A" coal	
Mount Morris limestone	
Waynesburg sandstone	

Pennsylvanian	
Monongahela group	370±
Waynesburg coal	
Waynesburg limestone	
Uniontown coal	
Benwood limestone	
Sewickley (Mapletown) coal	
Redstone coal	
Pittsburgh sandstone	
Pittsburgh coal	

In the above section the named beds in each group do not constitute the entire strata. On the contrary, shales predominate but the various shale strata have not been given specific names.

Distribution of the Geological Formations.

The geologic maps contained in the folios show the distribution of the various geologic formations. These show the Monongahela group outcropping in the eastern part of the county, along Monongahela River and appearing in the valleys of the tributaries for a distance of four to six miles. In the valley of Tenmile Creek the group outcrops to within a mile of Waynesburg. The group is also sparingly represented in the valleys of a few streams in the northwest corner of the county.

The Washington group of the Dunkard series occupies the divides in the vicinity of Monongahela River and extends up the tributaries as far west at Rogersville. It also appears in the valleys of the streams in the northwest portion of the county.

The western half of the county is almost entirely underlain by the Greene group with the exception of some of the valleys mentioned above. It is the most extensively exposed group of the County.

Descriptions of the Individual Limestones.

Benwood (Great) limestone.—The Benwood limestone is well exposed in the eastern part of the county along Monongahela River and its main tributaries, Tenmile Creek, Muddy Run, and Dunkard Creek. It is particularly well-exposed on Castile Run, at the bridge crossing Tenmile Creek, 2 miles northeast of Jefferson, and on Meadow Run southeast of Davistown. Throughout the greater portion of the county the Benwood limestone is concealed by younger strata. In a well boring in Center Township it was reached at a depth of 63 feet.

"The most important member of the Monongahela formation lithologically is the Benwood limestone, which in places attains a thickness of 150 feet, and has its base about 130 feet above the Pittsburgh coal. The name is derived from an excellent exposure of this limestone at Benwood, 4 miles south of Wheeling, W. Va. This limestone is commonly known as the Great limestone.

"The term Benwood limestone is restricted to the strata occurring between the Mapletown and Uniontown coals. This bed is never solid limestone, being broken up by layers of shale and thin sandstone into two large divisions. The lower division is about 60 feet thick, and is generally composed of alternating bands of limestone and calcareous shale. The limestone beds are usually less than 2 feet thick, although an occassional bed attains three to five times that thickness locally. The upper division of the Benwood limestone is of varying thickness, from 6 to 20 feet, and lies immediately under the Uniontown coal. It is composed of beds a foot or more thick with interstratified thin layers of shale. The lower division is more persistent than the upper and has a larger magnesian content. The analyses which are obtainable indicate that the composition is variable. Certain benches are pure enough for making lime, while others are worthless. The texture varies from very fine to shaly. This limestone has been used in the Monongahela Valley for manufacturing natural cement. The weathered surface of the limestone may be gray, almost white, bluish, or brownish; the fresh stone is dark blue, flesh colored, and drab."[54]

In general the Benwood limestone is suitable for agricultural lime but not for building lime. It has been used in the past in a limited capacity for the manufacture of natural cement but is too high in magnesium carbonate for Portland cement. Some beds contain material satisfactory for road purposes.

Waynesburg limestone.—"The interval between the Uniontown and Waynesburg coal is occupied by sandstone and shales, with a 10-foot bed of limestone 25 feet below the Waynesburg coal. This bed, which is known as the Waynesburg limestone, is persistent and can be found usually where the road crosses its horizon. It is light colored and fairly heavy bedded.

"The Waynesburg limestone, which is found from 20 to 40 feet below the Waynesburg coal, makes a strong, dark lime. It is exposed and readily accessible in a number of places in the quadrangle. Among these may be mentioned Braden Run a few hundred feet downstream from Kelly's coal bank; Browns Run near Fowler's coal bank; along south fork of Tenmile Creek near the covered bridge 1 mile southwest of Jefferson; on the road from Clarksville to Castile Run, going over the hills; on Whiteley Creek three-quarters of a mile east of Whiteley; and in the hollow three-quarters of a mile east of the mouth of Glade Run."[55]

Mount Morris limestone.—From 2 to 5 feet below the Waynesburg "A" coal, White (Bull. 65, U. S. Geol. Surv.) describes a limestone from 1 to 2 feet thick well exposed along Dunkard Creek near Mount Morris. It is not persistent throughout the County.

Calvin (Colvin's) Run limestone.—White also describes a fairly pure limestone about 3 feet thick overlying the Waynesburg "A" coal. It is named from Calvin Run which is a tributary of Dunkard Creek. The limestone is said to be high in iron in some places, to have a buffish cast, and to be unsatisfactory for lime because of poor slaking when burnt.

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[54] U. S. Geol. Survey, Folio 121, pp. 5-6, 1905.
[55] Op. cit. pp. 6, 12.

Lower Washington limestone.—The Lower Washington limestone is of little economic importance in Greene County although present in many places in the western part of the county. It occurs immediately above the Washington coal bed.

Section of Lower Washington limestone 1 mile northwest of Ryerson Station.[56]

	Ft.	in.
Limestone	1	8
Shale	1	1
Limestone	1	6

Blacksville limestone.—From 30 to 50 feet above the Washington coal White (op. cit.) describes a fairly pure, generally gray limestone from 3 to 5 feet thick that is especially well exposed in the Dunkard Creek region.

Middle Washington limestone.—The Middle Washington limestone is not important in Greene County. In the Dunkard Creek region it is about 3 feet thick and contains numerous fossils. The shales accompanying the limestone contain fish scales, teeth, and fossil plants.

Jollytown limestone.—"Thirty feet above the Jollytown coal and 20 feet below the Upper Washington limestone is a limestone which is exceedingly persistent. It is hard and coarsely brecciated, weathering to dull gray, often tinged with yellow. The surface frequently has a roughened appearance where weathered. Owing to its ability to withstand the weather and to its peculiar surface characteristics it is an important guide in stratigraphy. It is not more than 5 feet thick, but it is so resistant that some trace of it is usually found wherever it has been exposed. Outcrops are numerous. Along South Fork of Tenmile Creek above Waynesburg in particular, and throughout the western half of the quadrangle in general, blocks of the yellow limestone can be found between the Jollytown coal and the Upper Washington limestone."[57]

This limestone is usually regarded as of no economic value.

Upper Washington limestone.—"The Upper Washington limestone is by far the most conspicuous and persistent member of the Dunkard group in this region. Its position is from 350 to 440 feet above the Waynesburg coal.

"The characteristics of the Upper Washington limestone are so marked in this region that it is easily recognized. In all portions it weathers to a gray-white. This color is in such strong contrast to that of other limestones in this region that it affords a means of certain identification. In case of any doubt the occurrence of the yellow Jollytown limestone at its customary place 20 feet below is conclusive. The Upper Washington limestone in this section is from 4 to 15 feet thick. It is brittle, rings sharply when struck, and is divided into two or three layers by thin beds of shale. On fresh fracture the rock is blue, almost black, drab, and mottled. Its brittleness and ability to withstand the weather have led to its employment as road metal, and it is often burned for lime.

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[56] U. S. Geol. Survey, Folio No. 146.
[57] U. S. Geol. Surv. Folio 121, p. 6.

"The greatest thickness of this rock is seen near the Washington County line. Just north of the divide at the head of Craynes Run an excellent exposure was found in the road beside a small run. The limestone is 15 feet 6 inches thick, white on the weathered surface, and mottled gray inside. In the southern part of the county the bed is thinner, not so white, and outcrops are few.[58]

"Along Bates Fork, Browns Creek, Tenmile Creek, McCourtney Run, Hargus Creek, and Pursley Creek, in the eastern part of the Rogersville quadrangle, it presents its characteristic features. The limestone generally is from 5 to 10 feet thick and in some places forms two benches.

"Toward the west the Upper Washington limestone becomes thinner and less typical, and merges more and more into shale. At some places on Enslow Fork it forms two benches, but at the western edge of the County it has not been found. Over considerable areas it is absent or is doubtfully identified.[59]

"There is a typical outcrop of the Upper Washington limestone at the road forks on Wisecarver Run 2 miles north of the tin mill at Waynesburg. Also on Purman Run 2 miles north of Waynesburg, the Upper Washington and Jollytown limestones are exposed at the road forks. There are numerous outcrops of this bed along the road up Boyd, Hopkins, and Overflowing runs at an altitude of about 1100 feet, and on the hillsides farther east at greater elevations. The easternmost outcrop in Morgan Township is 2 miles west of Clarksville on a hill 1420 feet high, where the limestone has been quarried 60 feet below the summit. At the head of Dyers Fork on land owned by Mr. Zimmerman and on S. J. Bradford's farm across the ridge on the south, are good outcrops. In Wayne Township white blocks of Upper Washington limestone outcrop along Roberts Run at elevations of from 1100 to 1150 feet above sea level. An excellent exposure in the road ascending the ridge on the east a mile south of Spraggs shows the usual characteristics. The rocks rise to the east so that a 1400-foot hill near Davistown is lower than the horizon of the limestone. Almost no outcrop of this limestone could be found in the southern half of Whiteley and Perry townships. As a result of deep weathering of the soft sandstones and shales the surface is covered with a mantle of waste that may have hidden the outcrop, but it seems probable that at some places in the southern part of the County the limestone is absent.

"Professor Stevenson reported in 1876 that the interval between the limestone and the Washington coal varies from 325 feet on Dunkard Creek to 260 feet on South Fork of Tenmile Creek near Waynesburg and 190 feet on Ruff Creek in the eastern part of Washington Township".[60]

The Upper Washington limestone has been burned in many places for agricultural lime. The darker layers are said to produce a clear white lime suitable for plastering. In several places stone from this horizon has been accepted by the State Highway Department for the construction of water bound macadam roads. It has recently been quarried in several places a few miles southwest of Rogersville. A quarry about half a mile northwest of Swarts worked by the State in 1921, furnished the following section.

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[58] U. S. Geol. Survey, Folio 121, p. 6.

[59] U. S. Geol. Survey, Folio 146, p. 3.

[60] U. S. Geol. Survey, Folio 121, pp. 6-7.

Section exposed at Phillips quarry, ½ mile northwest of Swarts.

	Ft.	in.
Shale	1	2
Shale	6	0
Limestone	1	2
Shale	2	2
Clay	0	10
Shale	0	7
Limestone (best grade)	2	2
Shale	0	8
Limestone	1	3
Clay	0	2
Limestone	1	0
Yellow clay and shale	2	3
Limestone	1	0
Clay	0	2
Limestone	0	10
Clay	?	
Limestone	2	0

The limestone is soft, dove-colored, and breaks with a conchoidal fracture. Some of the layers of limestone appear to be hard and of good quality when quarried but disintegrate so quickly on exposure, due to a high argillaceous content, that they are worthless for road construction.

Limestones of the Greene group.—The Greene group, so well-developed in Greene County, contains a number of thin impure limestones, most of which are only local. The formation in the county has a maximum thickness of 700 to 800 feet and consists mainly of shales and sandstones with a few thin lenses of coal and limestone. Stevenson (Report K, Sec. Geol. Surv. of Pa.) has numbered 9 limestones. White (Bull. 65, U. S. G. S.) has given names to two of these layers.

The so-called Nineveh limestone lies about 105 feet above the Fish Creek sandstone. It is exposed along the North Fork of Dunkard Creek where it is 5 to 10 feet thick. It contains interstratified shale and weathers like shale. A few layers make good lime.

The Windy Gap limestone is present in the extreme southwest part of Greene County where it appears near the top of the highest hills. The limestone consists of several beds, aggregating 8 to 10 feet in thickness. It is a dark bluish to bluish black stone weathering to light gray. It has been found to contain minute fossils and occasional small crystals of zincblende.

Economic Importance.

This view of the limestones of Greene County shows plainly that the county contains an abundance of limestone that can be quarried in a small way to supply local needs for agricultural lime and certain layers furnish satisfactory material for highway construction. On the other hand it is evident that they will never be of more than local value.

WASHINGTON COUNTY.

Washington County is abundantly supplied with limestone; almost every square mile has limestone either outcropping or near the surface. The strata are interbedded with shales to such an extent that in some places the intervals named below as limestones may, in many localities, contain fully as much shale as limestone.

The geologic structures of the county consist of low anticlines and synclines and in few places do the strata dip more than a few degrees. The region is deeply trenched in all portions with steep-sided stream valleys thus furnishing numerous outcrops.

Generalized geologic section of Washington County.

Carboniferous.
Permian (Dunkard series) Feet
Greene group 425
Nineveh coal
Nineveh limestone
Claysville limestone
Dunkard (?) coal
Prosperity limestone
Tenmile coal
Donley limestone
Upper Washington coal

Washington group 400
Upper Washington limestone
Jollytown limestone
Jollytown coal
Middle Washington limestone
Blacksville limestone
Lower Washington limestone
Washington coal
Little Washington coal
Waynesburg "B" coal
Calvin (Colvin's) Run limestone
Waynesburg "A" coal
Mount Morris limestone
Waynesburg sandstone
Cassville shale

Pennsylvanian.		Feet
Monongahela group		360
Waynesburg coal		
Waynesburg limestone		
Little Waynesburg coal		
Uniontown sandstone		
Uniontown coal		
Uniontown limestone		
Benwood (Great) limestone	*Bulger limestone* *Dinsmore limestone*	
Sewickley coal		
Fishpot (Sewickley) limestone		
Redstone coal		
Redstone limestone		
Pittsburgh sandstone		
Pittsburgh coal		
Conemaugh group		500—
Little Pittsburgh coal		
Lower Pittsburgh limestone		
Connellsville sandstone		
Little Clarksburg limestone		
Morgantown sandstone		
Elk Lick coal		
Elk Lick clay		
Birmingham shale		
Berlin coal		
Ames limestone		
Friendsville or Harlem coal		
Saltsburg sandstone		
Bakerstown coal		
Brush Creek coal		
Mahoning sandstone		

The above section does not include all of the strata present in Washington County but only those that are fairly persistent and recognizable over considerable areas or those of some economic importance. The strata named comprise only a minor portion of those present, the bulk of the rocks consisting of unnamed shales and sandstones as well as many thin limestone beds. Also it must be borne in mind that few of the named beds extend over the entire county either as outcropping or concealed beds.

All of Washington County has been mapped since 1901 by the U. S. Geological Survey and the results published in Folios Nos. 94, 144, 146, 177 and 180. The above section and much of the data that follow have been compiled from these folios and Bulletins Nos. 65 and 249 of the same survey and Report K of the Second Geological Survey of Pennsylvania. These publications contain much information that cannot be incorporated in this report.

Distribution of the Geological Formations.

Reference to the geologic maps in the above-mentioned folios shows that the outcrop of the Conemaugh formation, the lowest in the county, is confined to the stream valleys in the northwestern part of the county, north of Washington, and to various places along the Monongahela River and the lower portion of its tributaries. Elsewhere the formation is concealed by later strata.

The Monongahela group appears at the surface in the northern and eastern portions of the county. It appears in the stream valleys almost as far south as Washington and forms a broad band in the Monongahela River Valley that extends westward in the tributary valleys to the vicinity of Benningsville, Emery, Vanceville, Three and Four, Beallsville, and Zollarsville.

The Washington group appears on the divides in the northwestern portion of the county as far south as Washington and in a wide band extending through Somerset and West Bethlehem townships. In addition it appears in most of the stream valleys in the southwestern portion of the county.

The Greene group, the latest of the Carboniferous strata of the county, forms the surface rocks, except in the deeper stream valleys of practically the entire area southwest and south of Washington.

Descriptions of the Individual Limestones of Washington County.

Ames limestone.—The lowest limestone outcropping in Washington County is the Ames which has also been known as the green fossiliferous and the crinoidal limestone. It is the greenish gray impure gnarly limestone containing abundant fossils, mainly crinoid stems and brachiopods, indicating its marine origin. It weathers to a dull gray. It is rarely seen with a thickness of more than 2 feet but in a few places it occurs in two benches with a total thickness of 8 feet. It has a very limited exposure in Washington County, the outcrops being mainly confined to the northwest portion of the county where it appears in the valleys of Aunt Clara Fork of Kings Creek, Kings Creek, and Harmon Creek. It is probably exposed along Monongahela River in the vicinity of Charleroi. It is of no economic importance.

Little Clarksburg and Lower Pittsburg limestones.—In the upper part of the Conemaugh group exposed in the northwestern part of the county there are several thin discontinuous limestones, two of which have received distinct names. They are of little or no value.

Redstone and Fishpot (Sewickley) limestones.—In several places the interval between the Pittsburgh and Redstone coals consists of limestones interbedded with shales. This is particularly true in the vicinity of Bulger. These limestones have been grouped under the name of the Redstone limestone. The stone is a high silica, high magnesian, argillaceous limestone of no value except for agricultural lime and of little value for that purpose. It has a dense noncrystalline appearance not unlike flint fire-clay. On weathering it breaks into small angular fragments showing conchoidal fracture.

The Fishpot or Sewickley limestone is a discontinuous limestone lens that is locally developed beneath the Sewickley coal. It is of little importance in Washington County.

Benwood (Great) and Uniontown limestones.—"Above the Sewickley coal is a series of strata, aggregating in places 160 feet, which was formerly called the 'Great limestone'; later, in accordance with the system of using geographic terms to designate geologic divisions, it was named the Benwood limestone, from the town of Benwood, W. Va., a short distance below Wheeling. The name Benwood was later restricted to the lower limestones of this interval and the name Uniontown, already in the literature, was retained for the upper limestone. It is in the restricted sense that Benwood is here used. Between the Benwood and Uniontown limestone members is a shale interval of 15 to 20 feet.

"In the Burgettstown and Carnegie quadrangles the Benwood member consists of several beds of limestone separated by thick layers of shale. To two of these limestone beds, which are valuable oil horizon markers, Griswold has given geographic names. The lower bed, of cream-white limestone, which lies 35 feet above the Sewickley coal, he has called Dinsmore, from exposures at Dinsmore, Washington County, Pa. The upper brown limestone bed he has called Bulger, from typical exposures at Bulger, Washington County. The Dinsmore limestone bed has a thickness of 4 feet and the Bulger limestone bed a thickness of 1 to 2 feet. These two limestone beds are separated by about 20 feet of shale, olive green at the top and reddish or yellowish below.

"Above the Benwood, separated therefrom by 15 to 20 feet of coarse calcareous shale, lies the Uniontown limestone member, of which four separate beds can generally be identified, though none of them are well developed in these quadrangles. The first consists of about a foot of solid limestone, which shows a yellow surface when weathered and is blue when freshly broken; the weathered surface always shows small protuberances, due to the presence of particles that are more resistant than the surrounding matrix, which give it the appearance of being covered with small pimples and make it easily recognizable. Ten feet above this limestone is another, about a foot thick; it is composed of two highly different materials, which on weathering produce a characteristic spotted surface which serves to identify the rock wherever found. From 16 to 18 feet above the last-mentioned bed is a blue limestone which on weathering has a white residue of clay upon its surface but is nevertheless easily distinguishable from other white limestone because the blue generally shows through the surface color. A foot or so above this bed is the top stratum of the Uniontown limestone member. On weathered outcrops this is a soft yellow limestone, but on fresh fracture it shows brownish red. It disintegrates readily and is seldom found in a solid ledge, its outcrop usually being marked by the presence of brown limestone nodules."[61]

These limestones are exposed in numerous places north of Washington. The top layers form the bed of Georges Run from Gretna to its mouth. They are exposed along Brush Run and Buffalo Creek in Hopewell and Blaine townships and at the mouth of Buck Creek, south of Acheson. At the Arden mines about 3 miles north of Washington a shaft passed through 51 feet of limestone. In Folio No. 180 of the U. S. Geological Survey the following section of the Uniontown limestone is given.

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[61] U. S. Geol. Survey, Folio 177, p. 4.

Section of Uniontown limestone member on road west from mouth of Georges Run in Canton Township, Washington County.

	Ft.	in.
Limestone, dark blue, very hard; weathers yellowish white	1	4
Shale, yellow	2	0
Limestone, yellow and hard, very impure	2	6
Limestone, steel gray; weathers yellowish to white	0	6
Shale, yellow	8	0
Limestone, yellow	0	3
Shale, yellowish	8	6
Limestone, buff, very hard; weathers black	2	6
Sandstone, thin bedded	3	0
Limestone, in several beds, steel gray; top bed pimply; bottom bed weathers in grooves and fantastic forms to yellowish-white color	3	0
	31	7

The Benwood is exposed in ravines northeast of Kammerer, in eastern Nottingham Township, in Union Township and in many other places.

These limestones are generally high in silicia, magnesium carbonate and argillaceous matter so that they are poorly adapted for flux, Portland cement, high grade lime, or for road metal. They have, however, been used locally for agricultural lime, for flux, in Fayette County for natural cement, and in various places stone of sufficient hardness for road metal has been obtained. For none of these uses, however, are they particularly well fitted and the bulk of the stone is of practically no economic value.

Analyses of Benwood limestone from Washington County, Pa.

	1	2	3	4
Insoluble residue	13.310	22.520	15.750	14.920
Calcium carbonate ($CaCO_3$)	68.837	48.823	47.080	47.750
Magnesium carbonate ($MgCO_3$)	14.649	20.621	28.728	30.913
Ferrous carbonate ($FeCO_3$)	3.306	3.625	7.511	5.068
Alumina (Al_2O_3)		3.523		
Sulphur	.697	.243	.069	.123
Phosphorus	.049	.051	.127	.015

1.—One mile north of Canonsburg Upper layer, very hard and compact, like conglomerate, bluish gray (Vol. K. 1876. p. 388; analysis by A. S. McCreath.)
2.—One mile north of Canonsburg: Middle layer, compact, somewhat shaly, color bluish gray (Loc. cit., analysis by D. McCreath.)
3.—One mile north of Canonsburg: Lower layer, hard, compact, unctuous, pearl gray (Loc. cit.; analysis by D. McCreath.)
4.—Property of Dr. Shaner, in Somerset Township, 8 miles from Washington (Vol. M2, p. 285; analysis by D. McCreath.)

Waynesburg limestone.—The Waynesburg limestone outcrops in various parts of the county but especially in the southeast. It occurs from 40 to 60 feet below the Waynesburg coal, and has a maximum thickness of about 20 feet and a minimum of about 4 feet. It contains some good stone.

Mount Morris and Calvin (Colvin's) Run limestones.—Below the Waynesburg "A" coal, is the Mount Morris limestone, between the Waynesburg "A" and "B" coals is the Calvin (Colvin's) Run limestone and above the "B" coal there are other thin beds of limestone not named. All of these are local and where developed are thin and of no importance except to yield a few tons for local use at or near the outcrop.

Lower Washington limestone.—"The lowest of the three principal limestones outcropping near Washington, and named after that town, generally forms the roof of the Washington coal. Occasionally, however, a few feet of shale intervene between the coal and the limestone. The Lower Washington limestone occurs from 150 to 220 feet below the top of the Upper Washington limestone. Washington County is the region of its best development, and here it sometimes attains a thickness of 30 feet. It is generally interstratified with much shale, as shown in the following section:

Section of Lower Washington limestone and associated shale on Smith Run.

	Ft.	in.
Limestone	9	6
Shale, black		5
Limestone		7
Shale, black		4
Limestone		1
Shale, black and soft		2
Limestone		2
Shale, black		2
Limestone, hard, blue-black, weathers white		9
Shale, soft, black	2	0
Fire-clay shale, dark		4
Bony coal		2
Shale, black		4
Fire-clay shale, dark		5
Total	15	5

"The Lower Washington is at most places a hard, compact limestone, which has a light blue-gray to fleshy color and usually weathers bluish white. The color is not distinctive, and in general it can be said that the color of none of the limestones in the Dunkard formation is a certain guide to the identity of the bed. The colors mentioned are characteristic, however, and usually assist in identification."[62]

Blacksville limestone.—White (U. S. G. S. Bull. 65) describes as the Blacksville limestone a generally gray, fairly pure limestone from 3 to 5 feet thick that is fairly persistent throughout portions of Washington County from 30 to 50 feet above the Washington coal. It is difficult to recognize in most sections.

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[62] U. S. Geol. Survey, Folio 144, p. 7.

Middle Washington limestone.—"Above the Lower Washington limestone occurs a thickness of 60 to 100 feet of shales and shaly sandstones. Occasionally this interval contains a thin bed of limestone. In places prominent sandstone beds occur locally. At the top of this interval and 100 to 140 feet below the Upper Washington limestone another bed of limestone generally occurs. It is a hard, compact, light-grayish or flesh-colored limestone, usually coarsely brecciated and containing numerous spots of crystalline calcite. This limestone generally can be recognized by the great quantity of iron it contains, which gives it a bright-yellow weathered surface. The weathered part frequently extends to a depth of several inches, and finally exfoliates and crumbles off. Some of the basal layers are more earthy and slaty and do not have this characteristic. The bed is in some places 10 to 20 feet thick. A trace of coal or black shale occurs at some localities in connection with the limestone.

"The Middle Washington limestone has a wide distribution in the county, but occurs in typical form near Washington. In a cut on the Baltimore and Ohio Railroad in the eastern part of the town the large yellow boulders from the bed are finely exposed. The upper or ferruginous part of the bed is richly fossiliferous, but the fossils are generally not identifiable. They are usually replaced by crystalline calcite and therefore can not be recognized on fresh fracture, and on the weathered surface their characteristics can not be determined. One of the best localities for fossils is the cut in the eastern part of Washington. Minute univalves and bryozoans and a diplodus-like tooth have been found here (Rept. K, p. 49)."[63]

"The Middle Washington limestone attains its greatest development in Independence, Canton, and Hopewell townships, where it is between 25 and 30 feet thick. It outcrops well toward the tops of the hills in both these townships and eastward into Mount Pleasant and Chartiers townships. It is finely exposed about half a mile north of the corner of Hopewell, Mount Pleasant, and Canton townships, as shown in the following section:

Section of Middle Washington limestone member on road from Buffalo to Gretna.

	Ft.	in.
Coal (Jollytown), shaly	0	6
Shale and sandstone	3	0
Limestone, yellow	0	3
Sandstone, reddish, and shale	10	0
Shale, soft, cream colored	5	0
Limestone, hard, blue	1	0
Limestone, slabby white	1	6
Shale	3	0
Limestone, gray, hard, and tough, fracturing flesh color	2	0
Shale	3	0
Limestone, single heavy yellowish bed, fractures flesh color with calcite crystals	2	0
Shale	2	0
Concealed.		

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[63] Op. cit.

"In Blaine, Buffalo, and Donegal townships this limestone is always present in outcrop, though it is thinner than in the townships toward the north, being in few places more than 20 feet thick. The heavy yellow ledge near the middle is as a rule prominently exposed and serves as an unfailing geologic marker, ranging from 70 to 82 feet above the Washington coal. Toward the southwest corner of the quadrangle, near Good Intent, this limestone appears to be represented by two or three thin layers embedded in brown shale."[64]

Jollytown limestone.—"In accordance with the usage of Stevenson (1876) and Stone (1905) the term Jollytown limestone is applied to the limestone occurring above the Jollytown coal and 30 to 40 feet below the Upper Washington limestone. It is a hard, grayish, sometimes brecciated limestone, weathering light gray to dirty yellow, and is a good guide to the geology. It is at some places several feet thick, and appears below the Upper Washington limestone on most of the roads in the southwestern part of the county.

Upper Washington limestone.—"The topmost bed of the Washington formation is the Upper Washington limestone, which, with the exception of the Waynesburg sandstone, is the most conspicuous and persistent member of the Dunkard group. For this reason it was chosen as the best horizon at which to subdivide the group into formations. It occurs 630 to 710 feet above the Pittsburgh coal and 280 to 400 feet above the Waynesburg coal. The variation is irregular, but in general the thinning of the interval from the Pittsburgh coal seems to be toward the northwest.

"The characteristics of the Upper Washington limestone are rather distinctive. It is hard, compact, and brittle, and is generally made up of a number of layers separated by thin beds of shale. Throughout the greater part of Washington County it consists, in its upper part, of a limestone which, on fresh fracture, is dark blue-gray, bluish black, or nearly black in color. Generally it contains drab and mottled layers. The rock as a rule is high in calcium carbonate. In some parts of the district is is easily recognized by its weathered surface, which is almost white, with a slight tinge of blue. It varies in thickness from 4 to 30 feet.

Section of Upper Washington limestone and associated rocks at tunnel 1 mile east of Washington.

		Ft.	in.
	Shale, dark, soapy	10	0
	Sandstone, hard, mottled, medium grained, gray	0	11
	Shale, black, sandy	1	9
Upper Washington limestone	Limestone, blue-black	2	3
	Shale, black	0	2
	Limestone, blue-black	0	10
	Shale	0	4
	Limestone, blue-black, brittle	1	10
	Shale, black	2	2
	Limestone, hard, gray, and thin shale	5	4
	Shale, soft, dark	0	6
	Limestone, light brownish gray, very hard, to level of railroad	3	6
	Total thickness of Upper Washington limestone	16	11

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[64] U. S. Geol. Survey, Folio 180, p. 6.

"The best exposures of this limestone are in the vicinity of Washington, where it reaches a thickness of nearly 36 feet. The tunnel of the Baltimore and Ohio Railroad 1 mile east of town cuts through the bed, exposing at its western end of the section given below. The limestone is quarried at this place.

"On Cemetery Hill, in the southwestern part of Washington the total thickness of the limestone is 30 feet, as shown in a section by Stevenson (Rept. K, p. 46). A good partial section of the limestone is exposed in a quarry one-half mile northeast of town, on the Williamsport Pike, where it is quarried and crushed for road metal. The limestone is well exposed on all the roads leading out of Washington toward the east and south, and outcrops at many points in the Nineveh syncline in South Strabane, northern Amwell, and South Franklin townships. In this region great care is necessary to avoid confusing it with a similar limestone which occurs 100 to 130 feet higher in the series. This limestone is also dark blue to black in color, and in thickness and other characteristics seems to be almost the exact counterpart of the Upper Washington.

"A good exposure of the Upper Washington limestone occurs in a quarry on the hill just southeast of Washington. The bed is here 15 feet in thickness. On the uplands in the vicinity of Mount Wheeler the limestone is deeply buried, but it appears again for about a mile between Vankirk station and Chambers dam, and south of McCracken station is exposed along Bane Creek from 100 to 200 feet above the floor of the valley. In the vicinity of Amity, and in general throughout the southern part of Amwell Township, it is high on the hills. South of Tenmile Creek it is overlain by 200 to 400 feet of rock. Its outcrop extends along the valleys and ravines for the entire distance between Dunne station and Bissell.

"Throughout West Bethlehem Township there are many outcrops of the limestone, but they all occur high on the hills, so that they appear on the map as mere patches. In the vicinity of Scenery Hill they are somewhat more extensive. One of the most continuous exposures of the limestone is on a long ridge on which a road runs in a northeast-southwest direction about midway between Daniels and Plum runs, west of Beallsville. The bed here seems to be at least 30 feet thick and numerous fragments of dark blue-gray limestone appear for several miles near the top of the ridge. It has been quarried on a knob about a mile west of Beallsville and on the National Pike one-half mile northeast of Odell. Near by, on the same hill, the thickness of the limestone appears to be as great as 50 feet.

"Near the middle of the Upper Washington limestone occurs a dark layer which contains great numbers of little bivalves and crustaceans. Fragments of mollusks also occur. The fossils are in general well preserved, but can rarely be broken out. This layer of the Upper Washington limestone gives a peculiar fetid odor when struck by a hammer."[65]

"The Upper Washington limestone underlies the southwestern half of the county, except narrow areas along valleys of the larger streams. It is also barely above drainage level on Tenmile Creek east of Prosperity and is exposed on Short Creek only in the vicinity of

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[65] U. S. Geol. Survey, Folio 144, p. 8.

Sparta. Up Tenmile Creek from Prosperity the outcrop of the Upper Washington limestone rises faster than the bed of the stream, and at the head of the valley it encircles the higher hills. It appears to be thickest at the type locality in the vicinity of Washington, thinning somewhat toward the northwest in Canton, Chartiers, Hopewell, and Independence townships. Southwest of Washington the lower portion of this limestone becomes variable and in places does not outcrop."[66]

All the Washington limestones have been quarried for agricultural lime and for road metal. The Upper Washington is especially valuable for these purposes and has been widely used.

Analysis of Upper Washington limestone near Washington, Pa.

Insoluble residue	17.380
Calcium carbonate ($CaCO_3$)	72.866
Magnesium carbonate ($MgCO_3$)	3.813
Alumina (Al_2O_3)	2.929
Ferric oxide (Fe_2O_3)	
Sulphur	.155
Phosphorus	.061

Sample from middle of bed; hard, compact, bluish gray limestone; conchoidal fracture. Vol. K., Sec. Geol. Surv. of Pa. p. 388, Analysis by D. McCreath.

Donley limestone.—"For the most widespread and uniform limestone in the Greene formation throughout the southwestern part of the county, the name Donley has been adopted. It is from 18 to 45 feet above the bottom of the formation, and is present where its horizon comes to the surface. In the vicinity of Donley Township, a typical section shows this limestone in three or four layers having a total thickness of 5 or 6 feet. The characteristic feature is its dark, rusty, lichen-covered surface when weathered. The limestone is very hard and tough and fractures unevenly with a dark steel-gray to almost black color, having a very coarse grain and showing numerous calcite crystals. The bed is also distinguished by its peculiar jointing, which has a striking resemblance to that of dry mud, the blocks being irregular in shape and from 1 to 3 feet in diameter. The joints are usually very distinct, many of them being from 1 to 3 inches wide and filled with dark-red residual clay. The Donley limestone is generally overlain by a light-gray laminated sandstone, 15 to 20 feet thick which locally becomes massive."

Prosperity limestone.—"Above the Tenmile coal is a rusty-yellow limestone, having a maximum thickness of 10 or 12 feet, which has been named the Prosperity limestone, from the village of that name in Morris Township. The top of this limestone is from 100 to 115 feet above the top of the Upper Washington limestone. The top layers are in places light bluish, fracturing irregularly with a dark-gray to rusty-black color, and are very coarse grained. The other layers are dark gray to buff on fracturing. This limestone is fairly persistent in the southwestern part of the County, being present on all the hillsides in the vicinity of Pleasant Grove. Its heaviest outcrop is northeast of Pleasant Grove, along the top of the ridge between East Finley and South Franklin townships."

Claysville limestone.—"From 205 to 225 feet above the base of the Greene formation is a limestone, separated into two layers by 6 to 8 feet of yellow shale. The top layer is 6 to 8 inches thick, bluish white, and dark brown on fresh fractures. The bottom layer is here and there as much as 18 inches thick, weathers with a rough surface to a reddish or yellowish color, and is dark gray on fracture. This limestone underlies a considerable area in the southwestern part of the county. In the northern parts of East and West Finley and Morris townships it is rather a compact bed, from 6 to 8 feet thick, the top layers being heaviest and all having a dark-gray color."[67]

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[66] U. S. Geol. Survey, Folio 180 p. 6.

Nineveh limestone.—Capping many of the highest hills in Morris and East and West Finley townships, there is a bluish white to cream limestone a few feet beneath the Nineveh coal that is called the Nineveh limestone. It contains 2 or 3 massive layers that are quite hard and tough.

Economic Importance.

The limestones of Washington County, although abundant and varied, are in the main, of inferior grade and do not compare favorably with those of other portions of the State or of adjoining States. However, their accessibility permits them to be extensively used throughout the county for highway construction and for lime. Individual beds possess the desired composition for the manufacture of Portland cement and it may well be that detailed investigations may discover some places where good stone may be obtained in large enough quantities and at sufficiently low expense to justify the erection of a cement plant, although no such locality is known to the writer.

WESTMORELAND AND FAYETTE COUNTIES.

Westmoreland and Fayette counties contain many limestones fairly well distributed. In the main they are impure and interbedded with much shaly material so that they do not form the basis for any extensive quarrying industry. Locally, however, they have been quarried in scores of places for the manufacture of agricultural lime and for road metal.

The strata of the counties were studied in considerable detail by the Second Geological Survey and described in Reports KK and KKK. Between 1900 and 1905 the central part of Westmoreland County and all except the eastern part of Fayette County has been surveyed by the U. S. Geological Survey and the results published in Folios 82, 94 and 110. Additional information is contained in Bulletins 65 and 249 of the U. S. Geological Survey.

From the above sources the generalized geologic section given below has been compiled. In the section only the members of economic importance or of especial prominence are given. The greater portion of the stratigraphic column consists of unnamed shales and sandstones. There are also occasional lenses of limestone, some of which in restricted areas may be of some importance, that are like wise omitted in the section.

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[67] U. S. Geol. Survey, Folio 180, p. 7.

Generalized geologic section of Westmoreland and Fayette Counties.

Carboniferous Feet.

Permian (Dunkard series)
Washington group .... 400+
Upper Washington limestone
Middle Washington limestone
Lower Washington limestone
Washington coal
Calvin (Colvin's) Run limestone
Waynesburg "A" coal
Mount Morris limestone
Waynesburg sandstone

Pennsylvanian

Monongahela group 400
Waynesburg coal
Waynesburg limestone
Uniontown coal
Uniontown limestone
Benwood (Great) limestone
Sewickley coal
Fishpot (Sewickley) limestone
Redstone coal
Redstone limestone
Pittsburgh sandstone
Pittsburgh coal

Conemaugh group 600
Pittsburgh limestone
Connellsville sandstone
Clarksburg limestone
Morgantown sandstone
Elk Lick coal
Elk Lick limestone
Ames (crinoidal) limestone
Saltsburg sandstone
Hager coal
Pine Creek limestone
Farmington coal
Brush Creek limestone
Brush Creek coal
Mahoning sandstone

Allegheny group 280
Upper Freeport coal
Upper Freeport limestone
Bolivar fire-clay
Lower Freeport coal
Lower Freeport limestone
Upper Kittaning coal
Johnstown (Cement) (Upper Kittanning) limestone
Middle Kittanning coal
Lower Kittanning coal
Brookville—Clarion coal

	Feet.
Pennsylvanian—Continued.	
Pottsville series	180±
Homewood sandstone	
Mercer coal group	
Conoquenessing sandstone	
Mauch Chunk series	250
Greenbrier limestone	
Mississipian	
Pocono series	400+
Loyalhanna (Siliceous) limestone	
Devonian	
Catskill group	400+

Distribution of the Geological Formations.

The oldest rocks of these counties, the Catskill, Pocono and Mauch Chunk, are entirely confined to the two prominent ridges, Chestnut Ridge and Laurel Hill, that extend through the eastern half of the counties from the West Virginia line to Indiana County, and to the valley of Youghiogheny River between these two ridges. The Pottsville sandstones are developed along the lower slopes of these ridges. The Allegheny and Conemaugh groups form most of the surface strata throughout the Ligonier Valley and outcrop over considerable areas in the western half of the counties. The Monongahela and Washington groups are confined to the western and northwestern parts.

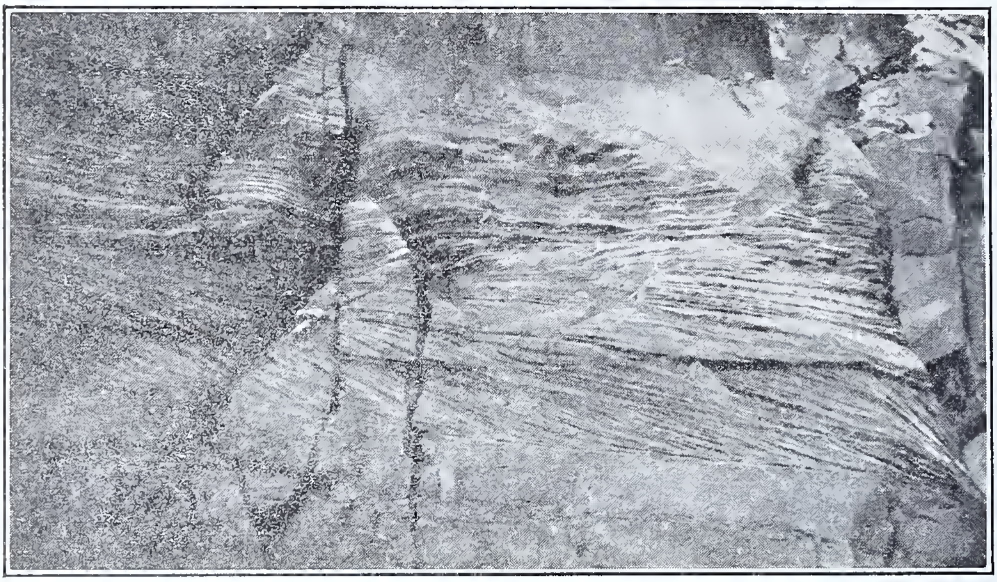
Descriptions of the Individual Limestones

Loyalhanna (Siliceous) limestone.—The Pocono series consists mainly of sandstone but near the top includes one bed that has been termed a siliceous limestone and given the name of Loyalhanna in recent years. It might equally well be called a calcareous sandstone and actually does grade downward into a true sandstone. It consists of grains of silica cemented by calcium carbonate. It is exposed in many places in Chestnut Ridge and Laurel Hill.

Along the Youghiogheny River, Loyalhanna Creek, and Conemaugh River it has been extensively quarried for railroad ballast. It is about 60 feet thick and grades upward and downward into true sandstones. It thins toward the southwest and is said to be only about 18 feet thick where it is crossed by the National Pike and no more than 4 feet at the State line.

In 1921 Childs quarry at Long Bridge along Loyalhanna Creek, 1 mile northwest of McCance post office was being worked by Booth and Flinn (Plate XIII), who are also operating a quarry along the Conemaugh River, 2 miles southeast of Blairsville Intersection At the former place the quarry face was about 2500 feet long. The calcareous portion is from 50 to 55 feet thick and is used both for railroad ballast and paving blocks. Some of the finer stone has been accepted by the State Highway Department for road construction.

PLATE XIII.



A. Loyalhanna limestone showing cross bedding, Booth & Flinn quarry, Long Bridge, Westmoreland County.

B. Loyalhanna limestone showing massive character, Booth & Flinn quarry, Long Bridge, Westmoreland County.

About two miles north of the National Pike along Beaver Creek this limestone has been quarried. Portions are said to have been burned for lime and to have made a good natural mortar but it is evident that in most places there would be an excess of sand. The lower part is red and the upper part gray.

Greenbrier (Mountain) limestone.—The Mauch Chunk series in Westmoreland and Fayette counties contains the Greenbrier limestone, formerly known as the Mountain limestone. This series is about 30-40 feet thick at the State line and gradually decreases northward. In the gorge of Loyalhanna Creek it is only about 3 feet thick. It lies about 50 feet above the Loyalhanna limestone and outcrops in both Chestnut Ridge and Laurel Hill. It has been quarried in many places for agricultural lime and in recent years for highway construction.

At the Thompson quarry (Plate XII, B) along the National Pike about 6½ miles southeast of Uniontown, where the State Highway Department has in recent years obtained much material for the roads and which was previously worked for agricultural lime, the following typical section is exposed.

Section of Greenbrier limestone 6½ miles southeast of Uniontown.

	Ft.	in.
Surface clay passing downward into green shale ..	3	6
Massive bed of hard limestone	1	8
Greenish, fossiliferous shale with thin streaks of limestone	2	0
Thick-bedded limestone	4	0
Dark-colored shale	1	6
Thick-bedded limestone	22	0
Argillaceous limestone	0	6

About 1 mile north of this locality along Beaver Creek two quarries have been worked recently to obtain material for small kilns. The beds are lithologically similar to those given in the above section but with material differences in thickness which seems to indicate considerable variation in the formation.

Johnstown cement limestone.—This member has also been called the Upper Kittanning limestone. It is exposed in several places in Westmoreland County and in a few places in Fayette County, although not persistent.. The most southern exposures known are on Laurel Run and Indian Creek in Springfield Township, Fayette County, where it is about 8 feet thick.

"Along the east face of Chestnut ridge this horizon is rarely exposed and no evidence of the presence or absence of the limestone was obtained until near the Conemaugh, where the rock is present as a hard, thin limestone, weathering very light blue and having no economic importance. Along the base of Laurel ridge it occurs with less irregularity having been seen on Indian creek in Donegal, on the Felger road between Donegal and Cook, on White Oak run in Cook, but in this township it is absent from Powder Mill run, where its place is held by ferriferous shale; in Ligonier it is absent from Linn's run and Furnace run but is present on Laurel run. Between the last two it alternately appears and disappears, while on Laurel run it disappears abruptly at barely two miles above Laughlinstown. Northward from this line it was not seen and it seems to be absent from Fairfield and St. Clair townships.

"This limestone is of much importance notwithstanding the irregularity of its occurrence. It is burned to supply lime for agricultural purposes, but, as it is often quite argillaceous, the burning must be carefully performed or much cinder will be produced."[68]

Lower Freeport limestone.—The Lower Freeport limestone is of little importance in these counties. It has been observed in Fayette County along the railroad at the west end of the Youghiogheny Gap through Chestnut Ridge where it is 2 feet thick. In Westmoreland County it is exposed in St. Clair Township and on Tub-Mill Run and along the railroad in Fairfield Township where it ranges from 2 to 4 feet in thickness.

Upper Freeport limestone.—The Upper Freeport limestone is the only important limestone member of the Allegheny formation of Westmoreland and Fayette Counties. The formation is exposed on both sides of Chestnut Ridge and Laurel Hill. Most of the exposures of this limestone are on either side of the Ligonier Valley. It lies from 5 to 15 feet below the Upper Freeport coal and has a maximum thickness of about 18 feet. In some places it is entirely absent and in other sections, only a few feet thick. In Henry Clay Township, Fayette County, it outcrops on both sides of Laurel Hill. In Wharton Township it is more than 10 feet thick on Big Sandy Creek near the State Line but absent along the National Pike. It is 6 feet thick along the headwaters of Big Meadow Run. It is well developed in Stewart Township both in the western part and along Jonathans and Cucumber runs. It is 18 feet thick on the hill above the mouth of Jonathans Run but only 3 feet thick at the northern edge of the township. It is irregular in the region north of the Youghiogheny River. Near Ohiopyle it is 9 feet thick. near Springfield from 3 to 5 feet thick, and in some places probably absent. North of Springfield it seems to be persistent to the Westmoreland County line.

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[68] Stevenson: Pennsylvania Second Geol. Survey Rept. KKK, p. 39, 1878.

"Following up the base of Chestnut ridge one finds this limestone fully 10 feet thick in Mount Pleasant township, Westmoreland County, 11 feet on Four-mile run and of unascertained thickness on the Loyalhanna, but on Tub-mill run in Fairfield township it is clearly wanting, while on the Pennsylvania Railroad in the same township it varies from zero to 10 feet. Along the base of Laurel ridge, this limestone appears to be absent or nearly so south from the Bedford pike, but at the pike some fragments of it were seen. On Hendrick's run it is 11 feet thick; on Tub-mill it is 14 feet, but only 3 feet 6 inches on Laurel Hill run while on the Pennsylvania Railroad it is wanting."[69]

Stevenson gives the following description of this limestone:

"This rock varies quite as much in quality as it does in thickness. At most localities it has on top a thin layer of dark blue impure slaty limestone, which is worthless, while the remaining portion is dull bluish gray with irregular fracture and more or less argillaceous. When burned hastily, it is apt to fuse, but if burned slowly it yields a lime, which does well for agricultural purposes, for which use it is highly valued. Oftentimes it is quite ferruginous at the outcrop and it was mined as an iron ore at Laurel Hill furnace. At some localities in Fayette it has been mistaken for iron ore and at the head of Jacob's creek a lean ore is associated with it."[70]

Ames (Crinoidal) limestone.—The Ames limestone is of little importance in this section. It is not present everywhere throughout the region but has been recognized in Springhill, North Union, Dunbar, and Perry townships, Fayette County, and in East Huntingdon, Hempfield, Penn, North Huntingdon, Salem, Washington, and Franklin townships, Westmoreland County. It is an impure highly fossiliferous greenish-gray limestone with a maximum thickness of about 4 feet.

The Conemaugh group of Westmoreland County locally contains several other thin limestones of little or no value, except in a very few localities. These are the Brush Creek, Pine Creek, Elk Lick, Clarksburg, and Pittsburgh limestones.

Redstone limestone.—Beneath the Redstone coal bed is the Redstone limestone that is well developed in the northern part of Fayette County, between Redstone Branch and the Youghiogheny River and in some parts of Westmoreland County, especially in Ligonier Township. Elsewhere it has been observed but rarely. It ranges in thickness from 10 to 20 feet. Locally it has been quarried for lime and for flux.

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[69] Op. cit. p. 33.

[70] Op. cit. pp. 33-34.

Analysis of Redstone limestone.

$CaCO_3$	66.471
$MgCO_3$	17.711
Carb. iron	5.178
Al_2O_3	.812
S	.080
P	.045
Insoluble	9.460

Sample from Lemont Furnace quarry, 3 miles northeast from Uniontown, Fayette County. Hard and brittle; sparkles with calcite; pearl gray, with conchoidal fracture. (MM, p. 289)

Fishpot (Sewickley) limestone.—Between the Redstone and Sewickley coal beds there are limestones, sandstones, and shales. About midway between the two coals is the Fishpot or Sewickley limestone. It is variable in thickness and characteristics. In places it is absent and elsewhere may be as much as 35 feet thick. It ranges from limestone of such impurity as to be worthless to fairly pure massively-bedded stone well suited for both lime and flux. It has been observed in various places in both counties.

Benwood (Great) limestone.—The Benwood limestone is the most prominent and persistent member of the Monongahela group in the region. It is as much as 85 feet thick in some sections although about half may consist of interbedded shales. Individual beds may be as much as 2 feet thick. No generalization can be made regarding its adaptability on account of its variable character. In one locality certain beds are sufficiently pure to be desirable for lime or flux whereas elsewhere the stone contains large quantities of siliceous and argillaceous matter. It has been extensively used in the production of agricultural lime for local consumption. Some of it is entirely satisfactory for road metal although much of it is too shaly.

This limestone member is present in almost every region where the Monongahela group appears, which is mainly in the western and northwestern parts of these counties.

Uniontown limestone.—The Uniontown limestone was formerly regarded as the upper portion of the Benwood but is now separated as a distinct member, although in certain places the exact correlation is difficult. In the vicinity of Uniontown it is a massively-bedded limestone in two layers aggregating 10 feet in thickness. Elsewhere it is somewhat thinner. It is well developed in Georges, North Union, South Union, Dunbar, German, Luzerne, Redstone, Menallen, Franklin, Jefferson, Washington, and Perry townships, Fayette County, and in Rostraver, South Huntingdon, Sewickley, and the south portion of North Huntingdon townships, Westmoreland County. Near Uniontown it was formerly quarried for the manufacture of cement that was used in the constuction of locks on the Monongahela River. It has been used for flux, for the manufacture of agricultural lime, and for road metal.

Waynesburg limestone.—About 20 feet below the Waynesburg coal is the Waynesburg limestone. It is best developed in German, Redstone, and Franklin townships, Fayette County, but also is present in North and South Union townships, Fayette County, and in Mt. Pleasant, Unity, and Derry townships, Westmoreland County, where it ranges in thickness from 8 to 35 feet. It produces a fairly good lime.

Limestones of the Washington group.—The Washington group is exposed on the tops of many hills in German, Redstone, Jefferson, Perry, North Union, and Dunbar townships, Fayette County, and in Rostraver and South Huntingdon townships, Westmoreland County, but contains very few limestones and those developed are thin and not persistent. The several limestones of this group that are so prominent in Greene and Washington counties have practically disappeared and shales are found at those horizons. In a few places in Redstone, German, Rostraver, and South Huntingdon townships, particularly southeast of Merrittstown, some thin limestones supposed to be the Lower and Upper Washington members have been noted. In the vicinity of Irwin, Westmoreland County, the Mount Morris and Calvin Run limestones have been noted.

Analyses of Carboniferous limestones of Westmoreland and Fayette Counties.

	1	2	3	4	5
$CaCO_3$	80.647	66.471	87.868	91.982	94.643
$MgCO_3$	2.217	17.711	1.733	1.664	1.144
$FeCO_3$	1.657	5.178	1.914	---------	---------
Fe_2O_3 and Al_2O_3	---------	---------	---------	1.520	2.720
Al_2O_3	.543	.812	.135	---------	---------
SiO_2	10.770	9.460	7.330	4.015	.990
S	---------	.080	.106	.091	.028
P	---------	.048	.050	.012	.015

1. Sewickley (Fishpot) limestone, Oliphant Furnace quarry, Georges Township, Fayette County. Report MM, p. 287.
2. Redstone limestone, Lemont Furnace quarry, 3 miles northeast of Uniontown, Fayette County. Report MM, p. 289.
3. Pittsburgh limestone, Lemont Furnace quarry, Report MM, p. 290.
4. Upper Freeport limestone, Wining and Cuisan's quarry, opposite Saltsburg, Westmoreland County. Report MM, p. 293.
5. Upper Freeport limestone, Kier Brothers' quarry, Salina, Westmoreland County. Report MM, p. 293.

SOMERSET COUNTY.

With the exception of a band of Catskill sandstone and Chemung shales outcropping in Savage Mountain, all of the surface rocks of Somerset County belong to the Carboniferous Period. Limestone lenses are numerous throughout, although, in the main, they are everywhere of little more than local importance as they cannot compete with thicker and purer limestones quarried in other regions. Nevertheless they have been utilized for agricultural lime by the farmers of the county.

In the course of this investigation it was not possible for me to make a study of the limestones of Somerset County. Report HHH of the Second Geological Survey of Pennsylvania contains many brief descriptions of the limestones. The following discussion of the limestones in Somerset County was written by J. D. Sisler of the State Geological Survey especially for this report.

Tentative geologic section of Somerset County.

PENNSYLVANIAN SYSTEM

	Feet
Pittsburgh series	
Monongahela group	200+
Uniontown coal	
Uniontown limestone	
Sewickley coal	
Fishpot (Sewickley) limestone	
Redstone coal	
Redstone limestone	
Pittsburgh coal	
Conemaugh group	600
Little Pittsburgh coal	
Lower Pittsburgh limestone	
Morgantown sandstone	
Elk Lick coal	
Elk Lick limestone	
Berlin coal	
Berlin limestone	
Platt coal	
Price coal	
Coleman coal	
Coleman limestone	
Philson (Rose) coal	
Philson limestone	
Johnstown iron ore	
Brush Creek (Gallitzin) coal	
Mahoning sandstone	
Allegheny group	300+
Upper Freeport coal	
Upper Freeport limestone	
Middle Freeport coal	
Middle Freeport limestone	
Lower Freeport coal	
Johnstown limestone (cement bed)	
Upper Kittanning coal	
Middle Kittanning coal	
Lower Kittanning coal	
Clarion coal	
Brookville coal	

	Feet
Pottsville series	?
Homewood sandstone	
Mount Savage coal	
Mount Savage fire clay	
Connoquenessing sandstone	
Sharon coal	
Mauch Chunk series	?
Greenbrier (Mountain) limestone	
Pocono series	
Loyalhanna (Siliceous) limestone	?

DEVONIAN SYSTEM

Catskill group
Chemung group

Many limestone beds outcrop in Somerset County. They have not been quarried on a commercial scale although there are several hundred pits opened by farmers who burn the lime for local farm use. The principal production of limestone for local kilns ended when the coal-mining industry reached such importance that many farmers abandoned the farms to work in the mines. In 1920 practically all of these old pits were abandoned.

Loyalhanna (Siliceous) limestone.—The correlation of the Loyalhanna and Greenbrier limestone in Somerset County is yet tentative, and this Survey will not commit itself until the detailed geological work is entirely completed for the Meyersdale quadrangle. The Loyalhanna limestone lies near the top of the Pocono series. It has been seen on Allegheny Mountain but it seems to be entirely lacking in large areas on Negro mountain. It is exposed in Laurel Hill along the western edge of the county, and has been used but little except in the gorge of Youghiogheny River. This limestone is easily identified by its siliceous, cross-bedded character. It ranges from a few feet to 20 feet thick. Its thickness increases northward from the southern Pennsylvania line. It is now being quarried for burning in the northeastern part of the county along the National Highway. Recently the State Highway Department has made tests, hoping to find certain portions of it suitable for road metal. The results of these tests have not been made public.

Greenbrier limestone.—This limestone occurs in two persistent benches, each ranging from 12 to 30 feet thick. The lower bench lies near the upper geological boundary of the Pocono series. The upper bench of the Greenbrier is usually separated from the lower by sandy shale ranging from 25 to 90 feet thick. This interval of sandy shale often contains thin beds of limestone which are highly fossiliferous. The top bench is usually gray in color and is locally very siliceous. The lower bench is a pure blue limestone which is often split into numerous benches by lenses of red shale.

Both benches of the Greenbrier were formerly quarried on the west slope of Negro Mountain in Elk Lick township, Somerset County. Mr. Peck is still quarrying this stone near Glade Mountain. The outcrop of this formation is extensive on the west slope of Negro Mountain but the limestone appears to thin very quickly northward. The northeast dip of the Negro Mountain anticline soon causes the limestone to disappear and it is not seen again until the Conemaugh River crosses it in Cambria County.

The lower bench of the Greenbrier is being quarried in Maryland near the Pennsylvania State line and just south of Greenville township, Somerset County. In this quarry the exposed limestone measures approximately 20 feet thick. The limestone dips very severely to the southwest on the eastern slope of the Allegheny Mountain anticline. It also appears to thin northward and its outcrop is seldom seen because the entire mountain is covered by many feet of drift. It was quarried prior to 1910 at one place in Greenville township. Its position can be readily traced by a very fertile belt of farm land.

Limestones of the Allegheny group.—The Vanport or ferriferous limestone of western Pennsylvania, having its normal position below the Lower Kittanning coal and a few feet above the Clarion, seems to be entirely lacking in Somerset County.

The Upper Kittanning coal is underlain by the Johnstown cement limestone. It is very persistent throughout Somerset County, averaging approximately 4 feet thick, and ranging from 2 to 8 feet. It is the most valuable geological marker in Somerset County. It has not been quarried commercially but has been opened locally for farm use. This limestone is usually gray or blue-gray, compact, and brittle. It is locally cross-bedded.

The Lower Freeport coal is locally underlain by a thin clayey limestone which is of no commercial importance whatsoever. The Upper Freeport coal, at the top of the Allegheny group, is invariably underlain by a bed of good limestone ranging from 2 to 7 feet thick. It is known as the Upper Freeport limestone. Although it has not been quarried for commercial purposes farmers have opened it at numerous points along the western slope of Allegheny Mountain and southeast of Somerset in the vicinity of Coleman School on the old plank road from Somerset to Berlin. In the northern part of Somerset County the Upper Freeport limestone is seen wherever the coal above it is mined. Its thickness seems to be irregular in this part of the county and its quality is variable. Locally it is very siliceous and is discolored by iron pyrite. Its most extensive outcrop is on the eastern flank of Laurel Hill and on the west flank of Allegheny Mountain.

Limestones of the Conemaugh group.—This group contains numerous thin limestones, only two of which may be of commercial importance in the future. The lower one, lying approximately in the center of the Conemaugh group, has been known in certain localities as the Elk Lick. In the publication of the Pennsylvania Geological Survey, Fourth Series, this limestone is called the Wellersburg after the nomenclature adopted by Dr. C. K. Swartz of the Maryland Geological Survey. Its type locality is Wellersburg, Maryland. This limestone ranges from 3 to 11 feet thick. The top of the limestone is generally very pure, but the bottom part is usually very clayey. At only one locality in Somerset County it is being recovered in conjunction with mining the coal above it. At this locality, on the eastern slope of Negro Mountain just west of Elk Lick, its outcrop is extremely promising. This bed of limestone has been found in practically every drill hole that has been put down in Somerset County.

A thicker limestone, the Clarksburg, occurs in two benches separated by approximately 20 feet of coal, shale, and sandstone. The top bench lies about 225 feet below the Pittsburgh coal and is the purer of the two. This limestone is present only in the Berlin-Salisbury basin of Somerset County where it has been preserved beneath the Pittsburgh coal. It occurs midway up the hill slopes in this basin and hundreds of tons have been quarried for local burning. Some lenses of this limestone are very pure, others are shaly and siliceous. Much of the lower bench is nodular, the nodules being cemented together by a soft calcareous clay. The nodules are very pure and are picked up on the slopes below the outcrops from which they have weathered and are piled and burned.

Limestones of the Monongahela group.—The Monongahela group contains two limestones, the Fishpot, or Sewickley, underlying the Sewickley coal, and the Uniontown limestone underlying the Uniontown coal. The latter has been entirely eroded in Somerset County. The former is present only in the high hilltops of the Berlin-Salisbury basin in the vicinity of Pinehill and south of Meyersdale on the western slope of Casselman River. This bed has not been quarried.

HUNTINGDON, BEDFORD AND FULTON COUNTIES

Practically all the outcropping Carboniferous strata of Huntingdon, Bedford, and Fulton counties are confined to the Broad Top region. A study of the coals of that region has been made by Dr. James H. Gardner[70] in which a detailed columnar section to the base of the Pottsville is shown. It includes a 3-foot bed of fine-grained bluish limestone in the Monongahela formation, two locally developed limestones in the Allegheny formation, probably representing the

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[70] Gardner, J. H., The Pennsylvania Broad Top Coal field. Top, and Geol. Survey Comm. of Pennsylvania, Rept. 10, 1913.

Freeport limestones of other districts. From all information available it seems that the Coal Measures limestones of the region are of little or no economic importance.

The Mauch Chunk red shale that is exposed as a band up to 3 miles wide surrounding Broad Top and extending northward in Little Trough Creek valley about 12 miles and southward a greater distance in the west part of Fulton County contains considerable limestone interbedded with shales. Most of the limestone is red and quite impure, containing up to 40 per cent of siliceous material, yet it has been utilized for agricultural lime locally. Some gray layers are purer. These limestones of the Mauch Chunk series seem to represent the Greenbrier limestone of the region on the west.

BEAVER AND ALLEGHENY COUNTIES.

As shown in the general geologic section that follows a number of limestone members occur in Beaver and Allegheny counties. Most of them are of little value, the important ones being the Vanport and the Benwood-Uniontown. Both are confined to rather limited areas yet they have furnished a large supply of stone that has been utilized for various purposes.

The geology of these counties has been studied by the geologists of the Second Geological Survey of Pennsylvania and the results published in Reports K and Q; by the geologists of the U. S. Geological Survey whose observations are contained in Bulletins 65 and 249 and in Geologic Folios Nos. 94, 134, 176 and 177; and by members of the present State Geological Survey.

The following section compiled from these sources shows the important strata but omits the numerous shale beds that constitute the major portion of the stratigraphic column in the two counties as well as numerous sandstones and a few unimportant coal and limestone lenses.

Generalized geologic section of Beaver and Allegheny Counties.

	Feet
Permian, Dunkard series	
Washington group	175±
Washington sandstone	
Little Washington coal	
Waynesburg "B" coal	
Calvin (Colvin's) Run limestone	
Waynesburg "A" coal	
Mount Morris limestone	
Waynesburg sandstone	
Cassville shale	

Pennsylvanian. Feet

- Monongahela group 260
  - Waynesburg coal
  - Little Waynesburg coal
  - *Waynesburg limestone*
  - Uniontown sandstone
  - Uniontown coal
  - *Uniontown limestone*
  - *Benwood limestone* { *Bulger limestone* / *Dinsmore limestone* }
  - Sewickley coal
  - *Fishpot (Sewickley) limestone*
  - Redstone coal
  - *Redstone limestone*
  - Pittsburgh sandstone
  - Pittsburgh coal
- Conemaugh group .... 500±
  - *Upper Pittsburgh limestone*
  - *Lower Pittsburgh limestone*
  - Connellsville sandstone
  - Little Clarksburg coal
  - *Clarksburg limestone*
  - Morgantown sandstone
  - Elk Lick coal
  - *Elk Lick (Barton) limestone*
  - Birmingham shale
  - Berlin coal
  - *Ames (crinoidal) limestone*
  - Friendsville (Harlem) coal
  - Saltsburg sandstone
  - Bakerstown coal
  - *Pine Creek (Upper Cambridge) limestone*
  - *Brush Creek (Lower Cambridge) limestone*
  - Brush Creek coal
  - Mahoning sandstone
- Allegheny group .... 325±
  - Upper Freeport coal
  - *Upper Freeport limestone*
  - Butler sandstone
  - Lower Freeport coal
  - *Lower Freeport limestone*
  - Freeport sandstone
  - Upper Kittanning coal
  - Middle Kittanning coal
  - Lower Kittanning coal
  - *Vanport (Ferriferous) limestone*
  - Bolivar sandstone
  - Clarion coal
  - Clarion sandstone
  - Brookville coal
- Pottsville series .... 225±
  - Homewood sandstone
  - Mercer coal group
  - *Mercer (Lower Wurtemburg) limestone*
  - Conoquenessing sandstone

Distribution of the geological formations.

All of the exposed geological strata of these counties belong to the Carboniferous and range from the Pottsville to the Permian. As in other sections of Western Pennsylvania, the Monongahela group contains most of the limestones.

The outcrops of strata belonging to the Pottsville series are confined to the northern part of Beaver County in the valleys of Beaver River and Conoquenessing Creek.

The Allegheny group in this region is likewise limited to the northern part of Butler County but is exposed not only in the valleys of the larger streams but also in many tributary streams.

The Conemaugh strata form the uplands throughout almost the whole of Beaver County and all the northern part of Allegheny County. In the southern portion of Allegheny County they are exposed in the stream valleys.

The Monongahela group is present on a few of the highest hills in the southern part of Beaver County and nearly all the uplands in the southern part of Allegheny County.

The Washington group is present on the tops of some of the uplands close to the Washington County line.

Mercer (Lower Wurtemburg) limestone.—The only limestone of the Pottsville series in the region is the Mercer limestone and it is confined to a very limited area in the northern part of Beaver County, along Beaver River and Conoquenessing Creek. It is only 8 to 12 inches thick and of no economic value.

Vanport (Ferriferous) limestone.—The Vanport limestone, formerly known as the Ferriferous limestone, because of its close association with a thin layer of overlying carbonate of iron ore, is the most valuable limestone of these two counties, although limited to the stream valleys in the northern part of Beaver County. It is much better developed in adjoining counties to the north and northeast.

The following descriptions are taken from the Beaver Folio (No. 134) of the U. S. Geological Survey:

> "This is the thickest and most largely exploited bed of limestone in the region, but because of its lenticular occurrence, which is common to all the limestones of this region, it is not everywhere sufficiently thick for working. It is characterized by its wealth of fossils, and, when thin, by cone-in-cone structure. Its position averages 65 feet below the Lower Kittanning coal. Hence, as compared with the coal it has a less extended outcrop, which is restricted to the deeper valleys (Ohio and Beaver rivers and Brady Run), and is covered more deeply and more often by gravel terraces.

"At Vanport the type section is 19 feet thick, and is given below:

Section of Vanport limestone at Vanport.

	Ft.	in.
Blue limestone	4	0
Shale	0	4
Blue limestone	8	0
Shale	0	6
Limestone	0	6
Shale	2	2
Hard ferruginous limestone	1	0
Shale	0	6
Fossiliferous limestone	2	0
	19	0

"The limestone beds differ very much both in color and quality. The first 9 inches are too impure to burn and are therefore stripped off and thrown away. The next 3 feet, together with the 8-foot layer below the shale parting, are burned for lime. The 3-foot portion is a bluish-gray rock in all of the quarries here and is extremely brittle, while the 8-foot layer, which is light gray or blue in color, is the purest and most compact limestone in the section. This portion burns to a very good white lime. The thin beds of the section are not used for lime.

"West of Vanport the limestone seems extremely variable, ranging from zero to 16 feet. A good thickness of 5 to 8 feet, however, is exposed between Vanport and Fourmile Run. Though the horizon remains above river level it is not seen again to the west, except south of Montgomery Island, where it is 16 feet thick. The terraces of Shippingport, north of Phillis Island, and at Georgetown cover the horizon with unconsolidated river gravels.

"East of Vanport the limestone attains considerable thickness only at Fallston, where it is 10 feet thick, but on the opposite side of Brady Run it thins to 18 inches. It maintains about this thickness throughout Brady Run, where exposed, and on upper Beaver River, but east of New Brighton and to the south on both sides of the river it is 3 to 4 feet thick. At Monaca, however, though the rocks between the Lower Kittanning coal and river level, a distance of 60 feet, are uncovered, the Vanport limestone is not revealed. It may be below water level.

"The localities where this limestone is most accessible for mining are along its outcrop on the north bank of Ohio River and in Beaver Valley. The occurrence south of Montgomery Island is practically inaccessible. On the whole the Vanport is the only bed in the region which is in places pure enough to produce good lime or to be used in fluxing.

Analyses of the Vanport limestone.

	1	2	3	4
$CaCO_3$	93.482	88.464	91,607	91.089
$MgCO_3$	1.544	1.445	1.566	1.587
Fe_2O_3 Al_2O_3	1.823	2.324	1.291	1.589
S	.030	.097	.290	.047
P	.047	.029	.030	.040
Insoluble residue	2.770	7.030	4.780	4.800
	99.696	99.389	99.564	99.152

1. Severn's quarry, half a mile below Vanport, New Brighton township. Upper bench.
2. Powers' quarry, near Vanport, on the Ohio river. Top stratum.
3. Powers' quarry, middle stratum.
4. Tygart's quarry, half a mile below Vanport. Lower stratum.

Lower Freeport limestone.—The Lower Freeport limestone is confined to the northern part of Beaver County. It lies a few feet below the Lower Freeport coal, and is an impure fine-grained, buff-colored, non-fossiliferous rock. It occurs in lenses, hence is absent in many places. Where developed it is generally from 3 to 9 feet thick. The best stone is in the Beaver Valley near Beaver Falls, along Brady Run, and in a few other valleys. It is locally quarried and burned for agricultural lime.

Upper Freeport limestone.—The Upper Freeport limestone lies a few feet below the Upper Freeport coal. It occurs in lenses, hence is absent in many localities where it might be expected. It is confined to the northern part of Beaver County. Along Blockhouse and Brady runs it is from 2 to 3 feet thick; at head of Dry Run, 2 to 7 feet; west of Hog Island, 3 feet; Monaca, 5 feet; and at the mouth of Raccoon Creek, 4 feet.

It is generally impure and suitable only for agricultural lime although there are a few places where a much purer bluish rock occurs suitable for the manufacture of building lime.

Limestones of the Conemaugh group.—The Conemaugh group of Beaver and Allegheny counties contains a number of thin, impure and non-persistent limestones, that in certain sections, have been utilized for agricultural lime but, in general, are worthless. Those that have received names are the Brush Creek (Lower Cambridge), Pink Creek (Upper Cambridge,) Ames (crinoidal), Elk Lick (Barton), Clarksburg, Lower Pittsburgh, and Upper Pittsburgh. Most of the following brief descriptions have been furnished by M. E. Johnson of the Pennsylvania Topographic and Geologic Survey from his field observations in the Pittsburgh quadrangle.

The Brush Creek limestone has been noted in only a few localities. South of McKeesport it is exposed on both sides of the Youghiogheny River. It is very sandy and about 10 inches thick. It is also developed along the Allegheny River east of Pittsburgh and at Witmer. The maximum thickness observed was 20 inches.

The Pine Creek limestone is exposed at Witmer and a few points along the Allegheny River. It is an impure, nodular fossiliferous limestone from 2 to 10 inches thick.

The Ames limestone is the most persistent of the limestones of the Conemaugh formation. It varies from 6 to 30 inches.

"The limestone ordinarily has a typical greenish gray to gray color. Where it has undergone much weathering it may present a greenish-brown appearance, but this condition was seldom observed. It is tough, impure, exceedingly fossiliferous, and always presents a rough surface—either when weathered or freshly broken. Often the limestone is present only as a single bed ranging from 5 to 10 inches thick. Where it is more fully developed it may occur as two or three beds in close proximity, the beds being separated by a thin clay or clay-shale. Due to the fact that the strata immediately above and below the Ames are soft and easily weathered, it is common to see the Ames jutting out prominently in railroad cuts and other excavations where its horizon has been uncovered.

"Because the Ames limestone is usually thin and impure it has seldom been used as a source of agricultural lime. A few farmers reported that they had burned the Ames to obtain lime, but that it was very unsatisfactory. None of them kept up the practice."

The Elk Lick limestone occurring just beneath the Elk Lick coal and the Clarksburg limestone below the Little Clarksburg coal are doubtfully present in these counties. In any case they are poorly developed and of no importance.

The Pittsburgh limestones include variable non-persistent beds that may be developed within a few feet of the Pittsburgh coal or 60 to 70 feet below. They may be absent altogether, or be developed as any number of beds up to eight.

"The character of the limestone beds also varies considerably, although in general it can be said that the beds decrease in purity as the interval between the limestone and the Pittsburgh coal becomes less. Often there is a limestone bed within six inches of the base of the Pittsburgh coal. Where it occurs this limestone is always very impure and is usually stained a dark gray by carbonaceous material. The limestones close to the base of the Pittsburgh coal sometimes contain ferruginous concretions. This is the exception rather than the rule, however.

"In the southeast part of Allegheny County there is a very massive characteristically stained limestone (rusty brown stains on creamy-gray limestone) found about 30 to 35 feet below the Pittsburg coal. This limestone is hard and compact and is easily traced where it is present in the section. Unfortunately it disappears towards the north. This massive bed has been quarried by the farmers who report that it makes an excellent lime."

Redstone and Fishpot limestones.—The lowest limestone members of the Monongahela group, the Redstone and Fishpot, are present in several places in the southeast portion of Allegheny County, particularly west of the Monongahela River. They are very thin, light gray to buff in color, compact, homogeneous and pure or nodular and impure. They are both of fresh-water origin and of little economic importance.

Benwood and Uniontown limestones.—The Benwood, sometimes divided into Bulger and Dinsmore beds, and the Uniontown limestones are the best developed limestones of these counties although almost entirely confined to the southern half of Allegheny County. Although described by some observers as regular in their characteristics, M. E. Johnson states that in Allegheny and Westmoreland counties the various beds seldom exhibit similar qualities, and he finds difficulty in making definite divisions. The following descriptions are furnished by him from unpublished manuscript.

"West of the Monongahela River the Benwood group is represented by only a few beds, the total thickness of which may be ten feet or less. Towards the southeast the total thickness rapidly increases until at Cowansburg, Westmoreland County, we have a thickness of 150 feet, that is, the section for 150 feet largely consists of limestone of the Benwood and Uniontown members. The total thickness of limestone would probably be less than 100 feet.

"The top member is often a dark gray limestone with considerable carbonaceous material in it. On the other hand in one section the topmost limestone was an impure, easily weathered, buff-colored limestone containing considerable clay and no carbonaceous material.

"Without attempting to describe each type of limestone bed encountered, it can be said that generally the limestones are fairly pure and that they range from light blue-gray, pure limestones to buff colored or dark gray limestones containing a large percentage of impurities. As a general rule the impure limestones weather more readily than the pure ones. Sometimes the limestones contain veins and small vugs filled with calcite crystals.

The limestone bed which seemed to be most persistent and widespread, was a massive, hard, brittle limestone with a mottled, brecciated appearance on fresh fracture. This bed occurred persistently in the lower part of the group. Another limestone bed which could easily be picked out was found in certain areas. This was impure, slaty limestone greatly resembling the cement rock of the eastern part of the State. Unfortunately its occurrence was not widespread.

"The Dinsmore limestone is described in various publications as a group of limestone beds occurring at the base of the Benwood group which weather out to a characteristic creamy-white color. Either the Dinsmore limestone is frequently missing from the section in this territory or else this description is not applicable. Certainly the lower members of the group as often as not weather to a buff color rather than a creamy-white. Again, the lower member is often a compact, gray limestone showing little indication of weathering.

"Taken as a whole this group of limestones presents by far the largest available source of limestone in the two counties. At many places small quarries have been opened and the limestone crushed and used for road metal. Many farmers burn the stone for fertilizer. It has also been used at times for building purposes. The supply is practically unlimited."

Waynesburg limestone.—The Waynesburg limestone has a very limited development in the southeastern part of Allegheny County where between the Monongahela and Allegheny rivers it consists of a dark blue limestone about 18 inches thick.

Limestones of the Washington group.—As stated above the Washington group has a very limited development in the southern part of Allegheny County. The Mount Morris and Calvin Run limestones may be locally developed although no information is available concerning them. The Washington limestones which are so important in the counties to the south are not present in Allegheny and Beaver counties, having been removed by extensive erosion.

MERCER, VENANGO, BUTLER AND LAWRENCE COUNTIES.

Unlike some of the southern counties, Mercer, Venango, Butler, and Lawrence counties contain few limestone beds. However, this is in a manner offset by the extensive development of the Vanport, the most valuable limestone of Western Pennsylvania, and by the presence of the Freeport limestones, also of fair quality, throughout the counties.

The geology of these counties has been described in Reports Q, QQ, QQQ, and V of the Second Geological Survey of Pennsylvania and in manuscript reports of the present State Geological Survey prepared in 1919 in connection with a study of the road-building materials of the State.

The following stratigraphic section of the principal members present in these counties, omitting most of the shales and many of the sandstones, is compiled from these reports. Most of the members are not persistent throughout the counties and any of them may be locally missing.

General geologic section of Mercer, Venango, Butler, and Lawrence Counties.

Conemaugh group
  Morgantown sandstone
  Elk Lick coal
  Ames (crinoidal) limestone
  Red shales
  Bakerstown coal
  Pine Creek limestone
  Buffalo sandstone
  Brush Creek limestone
  Brush Creek coal
  Mahoning sandstone

Allegheny group
- Upper Freeport coal
- *Upper Freeport limestone*
- Upper Freeport fire-clay
- Upper Freeport (Butler)sandstone
- Lower Freeport coal
- *Lower Freeport (Butler) limestone*
- Lower Freeport sandstone
- Upper Kittanning (Darlington) coal
- Middle Kittanning coal
- Lower Kittanning coal
- Kittanning fire-clay
- Kittanning (Industry) sandstone and shale
- Clarion iron ore
- *Vanport (Ferriferous) limestone*
- Scrubgrass coal
- Clarion coal
- Fire-clay
- Brookville coal

Pottsville series
- Homewood (Piedmont or Tionesta) sandstone
- Tionesta coal
- Tionesta iron shales
- *Upper Mercer, (Mahoning, Upper Wurtemburg) limestone*
- Upper Mercer coal
- Upper Mercer iron shales
- *Lower Mercer (Lower Wurtemburg) limestone*
- Lower Mercer coal
- Lower Mercer iron shales
- Upper Conoquenessing sandstone

Mauch Chunk series
- Quakertown coal
- Quakertown iron shales
- Lower Cononquenessing sandstone
- Sharon iron shales
- Sharon coal
- Sharon conglomerate
- Cuyahoga (Shenango?) shale

Pocono series
- Shenango sandstone
- Crawford shales
- Sharpsville sandstone
- Orangeville shales

Descriptions of Individual Limestones.

Lower and Upper Mercer limestones.—The Pottsville series of these counties contains two limestones of little economic importance. They are well developed in Mercer and Lawrence counties where they have been quarried locally in many places but in Butler county, although recognized in several places, particularly in the Beaver Valley, are too thin to be of any value.

In Lawrence County the Lower Mercer limestone is one of the most persistent members of the Pottsville series. It lies from 110 to 135 below the Vanport limestone. Although of varying thickness it is more generally from 2 to 2½ feet thick. It is dark blue, highly fossiliferous, and breaks with a conchoidal fracture. Carbonate iron ore is developed in association with the limestone and in some cases both iron ore and flux from this horizon were obtained during the time when the carbonate ores of Western Pennsylvania were being worked.

The Lower Mercer limestone is even better developed in Mercer county. In places it passes into a carbonate of iron ore. White[71] describes it as "always a dark gray or bluish rock, blue predominating; sometimes slaty, splitting off in thin plates or slab-like pieces; always richly fossiliferous, and especially rich in mollusks and crinoids, the broken stems of which often make up a considerable part of the mass." It is present throughout the county ranging from 2 to 4 feet in thickness. It has been quarried for lime, although not well adapted for this purpose, and was formerly quarried locally for flux for some of the local furnaces.

The Upper Mercer limestone is of little importance in Butler County. In Lawrence County it is better developed and was seen at many places in the valleys of Beaver, Mahoning, and Shenango rivers and Slippery Rock Creek. It varies considerably in thickness but is usually from 2 to 4 feet thick. It is a very hard compact, dark blue fossiliferous limestone. Iron concretions are common.

One half mile south of Mount Jackson is an outcrop of the Mercer limestone in the bottom of Hickory Run. The formation here is 2 feet thick and consists of dark blue, rather impure slaty limestone, and is hard and resistant. The stream cascades over it at this point. Below the limestone is a bed of impure, slaty coal 18 inches thick, followed by sandstone. A short distance down the stream the limestone rests on about 8 feet of black shale. The Vanport limestone should occur above it at an elevation of 1060-1080 feet. No outcrops of it, however, were discovered in this region south of Mt. Jackson. The Mercer limestone is better developed here than at any other point in Lawrence County where it was examined. Another good exposure of the Mercer limestone is to be seen just east of Wurtemburg along Slippery Rock Creek where it measures 12 to 14 inches. Beneath it occurs 12 to 18 inches of coal. The limestone here is in the form of a lens that thins out both ways to zero. Above this limestone at an elevation of 1050 feet occurs the Brookville (?) coal, which is 30 inches thick. This would put the Vanport limestone at an elevation of approximately 1100 to

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[71] Pennsylvania Second Geol. Survey, Rept. QQQ, p. 41.

1120 feet. In the extreme southeast corner of the county, the Vanport limestone could not be found, but time did not permit of a careful search for it.

The Upper Mercer limestone has been observed in a few places in the southern part of Mercer County where it is about 2 feet thick. It was at one time quarried for flux.

Vanport limestone.—In the summer of 1919, C. R. Fettke and E. G. Hill, Carnegie Institute of Technology, working in Butler and Venango counties and F. B. Peck, Lafayette College, in Lawrence County collected much information concerning road-making materials for the State Highway Department. Their investigations were mainly confined to the Vanport limestone. Portions of their reports are incorporated in the following pages. In reading their descriptions it must be borne in mind that they were written in 1919.

Vanport limestone of Butler and southern Venango counties.

By C. R. Fettke and E. G. Hill.

GENERAL LOCATION OF OUTCROP.

Outcrops of the Vanport appear along Slippery Rock and Wolf Creeks and on the steep hillsides, but crops of the full thickness of the formation are rare. The exposed faces are rugged and broken, the horizontal and vertical joints widened by exposure and action of percolating waters through the mantle of residual soil usually found as a cover. Most of the Vanport is underlaid by impervious beds of shale, and surface waters penetrating the limestone through its vertical joints find outlet in numerous springs. These springs assist the prospector in locating the outcrops.

Outcrops appear in Winfield Township, Butler County, along Rough Run and Buffalo Creek over a restricted area, which is being extensively mined by the Pittsburgh Limestone Company. The limestone here is about 19 feet thick but within half a mile is entirely lost. Going northward and westward, outcrops are next encountered in Muddy Creek Valley, Muddy Creek Township, extending eastward from the Lawrence County line and northward into Worth Township. Quarries have been operated in this district on faces from 15 to 21 feet thick, and the indications are that the limestone has a thickness of at least 15 feet over the entire area. At some points the formation is deeply covered by glacial deposits.

Going north, the limestone again crops in the Slippery Rock Valley, near the line between Butler County and Lawrence and Mercer counties extending from the vicinity of Jacksonville in Worth Township northward to the junction of Slippery Rock and Wolf Creeks, thence eastward along Slippery Rock Creek and its tributaries into Slippery Rock and Brady Townships, then northward along Wolf Creek through Slippery Rock Township into Lawrence County. The stone in these localities has not been extensively quarried or mined. Small quarries on the farms and the history of wells in the neighborhood indicate a thickness of the formation ranging from 10 to 18 feet. At the northern end of the area across the county line in Lawrence County, large quarries were opened on faces from 15 to 18 feet thick but have not been worked for a number of years.

Leaving the valley of Wolf Creek and going northward, no further outcrops appear until near the vicinity of Swamproot village, in Pine Township, Mercer County, where small abandoned quarries show 12 to 14 foot faces. Northeast of Grove City, toward the Butler County line, limestone is found as shown by small quarries and wells, in which the stone is from 4 to 6 feet thick and at other points nearby appears to be entirely absent.

Returning to the junction of Wolf and Slippery Rock creeks and traveling eastward through Slippery Rock, Brady and Marian townships and into Cherry Township along the valley of Slippery Rock Creek and its tributaries, Hogue Run, Big Run, Glade Run, McDonald Run,, South Branch, Findlay's Run, McMurray's Run, North Branch, Black's Creek and Seaton Creek, the limestone is found in many places outcropping in the gorges of the stream. Boulders and small quarries show a thickness of bed running from 9 to 17 feet. Along McDonald Run there are two large open quarries in which the faces are from 12 to 18 feet thick under a shale and clay cover from 20 to 26 feet in depth. Along the South Branch of Slippery Rock Creek at Osborne Station a large quarry operates on a face 600 feet long and from 16 to 17 feet high. Several miles eastward along the stream a mine is working on a 20 foot formation under 38 feet of sandstone and shale. Along McMurray Run a large quarry is operating on a face from 13 to 18 feet thick, and a mile and a quarter north of the quarry, the rock is being mined under about 41 feet of cover.

In the fork of Slippery Rock and Black's creeks, east of Black's Creek and north of Slippery Rock Creek, the limestone has been extensively quarried along a face 1400 feet long and from 14 to 18 feet high.

On the eastern side of the district in the valleys of the tributaries of Allegheny River, the southernmost outcroppings appear along Bear Creek and its tributaries, South Branch, Middle Branch and North Branch, in Parker and Allegheny townships. The principal outcrops are just west and northwest of Parker's Landing, on the properties of R. G. Morgan, Evan Griffith, and the Fox Estate. The beds in this vicinity show a thickness of about 10 feet or less, and there are no evidences of any extensive quarrying.

Further north, in the valley of Little Scrubgrass Creek, also a tributary of Allegheny River, in Scrubgrass and Clinton townships in Venango County, and in Venango and Allegheny townships, Butler County, a number of outcrops appear, but probably nowhere does the bed exceed 10 feet except at a point one mile north of Anderson Stone House where a thickness of 15 feet was measured. There is no evidence of extensive quarrying in this locality. Further west, in Irvin Township, Venango County, outcrops appear in the valley of Scrubgrass Creek, but nowhere to a greater thickness than 10 feet. There has been no extensive quarrying, but a small quarry is open and in operation on the Boyd Harris farm, two-thirds of a mile east of Mechanicsville.

QUARRIES IN OPERATION IN 1919.

1. *Branchton Limestone and Ballast Co.*, in the northeastern part of Slippery Rock Township, Butler County, along McDonalds Run. This quarry has a face 2600 feet long, 18 feet high, and is fully equipped for large operation. It is on the main line of the B. & L. E. Railroad, near Branchton Station.

2. *Pittsburgh Limestone Co.*, Harrisville, in the southeastern part of Mercer Township, Butler County. This quarry has a face 1674 feet long and 15 feet high, and has a capacity of about 250 tons per day. This company also operates a mine in the same vicinity with a capacity of 400 to 500 tons per day. It is fully equipped but does not at present produce stone for road work. This quarry and mine are situated on the main line of the B. & L. E. Railroad near Harrisville Station.

3. *Pittsburgh Limestone Co.*—Mine near Avondale Station, Marian Township, Butler County. This is a large operation fully equipped. This mine is located at Hilliards Branch, along the B. & L. E. Railroad.

4. *Climax Limestone Co.*—Along McDonalds Run in Slippery Rock Township, Butler County. This quarry operates on a face 1176 feet long and 13 to 17 feet high. It has full equipment for stripping, quarrying and loading stone. It is along the main line of the B. & L. E. Railroad near Wick Station.

5. *Grove City Limestone Co.*—Near Osborne Station, Cherry Township, Butler County. This company has opened a face 600 feet long and 16 feet high. It has a quarry equipment suitable for modern operations, and has also a crushing plant which is now used solely for lime products. It has a present operating capacity of 200 tons a day, which by lengthening the quarry face and adding to the equipment, might be increased to 1000 tons per day. It is situated along Hilliards Branch on the B. & L. E. Railroad.

6. *Pittsburgh Limestone Co.*—Mine at West Winfield, Williams Township in Butler County. This is an area extensively operated and fully equipped with the various mining appliances and a crusher. It is situated along the Winfield Railroad, a branch of the Pennsylvania Railroad running to Freeport.

7. *Quarry of Joseph Cooper* in Worth Township, Butler County, 1¼ miles south of Jacksville. This is a small operation working on a 17 foot face with equipment suitable only for a small output. There is, however, a large quantity of stone available at this quarry if the face was lengthened and modern facilities for quarrying and crushing provided. At present this quarry must haul its output three miles to the railroad at Portersville Station on the B. & L. E. Railroad or three miles to the nearest State highway.

QUARRIES IDLE IN 1919.

Muddy Creek Township, Butler County.

1. Quarry of New Castle Portland Cement Co., three-fourths of a mile south of Payne. Thickness of face 17 feet; possible length of face 18,000 feet; maximum cover 35 feet; available quantity 2,250,000 tons; transportation facilities, siding graded to Bessemer and B. & L. E. Railroad at Payne. Track must be relaid.

2. Quarry of Pittsburgh Limestone Company. At Portersville Station. Average thickness at face, 14.7 feet. Present length of face, 400 feet, but can be greatly extended; cover, about 24 feet; available quantity, 1,800,000 tons. Transportation facilities, siding on western Allegheny branch of the B. & L. E. Railroad at Portersville Station.

Worth Township, Butler County.

3. Quarry of Clyde Rennick on west bank of Slippery Rock Creek, one-half mile north of Kelly's Bridge. Thickness of face, 15 feet or more; cover, 10 to 19 feet; quantity undetermined. Transportation facilities, road haul ¾ mile to county road and two miles to State highway.

4. Quarry on farms of J. B. Studebaker, and G. F. Gardner, east of Eight Square School. Thickness of face, 15 feet; cover very light; available quantity, 1,320,000 tons. Transportation facilities, one mile haul to State highway at Elliott's Mill over a good dirt road.

Brady Township, Butler County.

5. On south side of Hogue Run ⅓ mile west of West Liberty, on the property of S. S. Hogue. Thickness of face, 16 feet; cover, 11 to 30 feet over an area of 1000 by 100 feet; available quantity, 135,000 tons; poor transportation facilities; available only for local improvements.

6. Quarry of C. E. Smith, three-fifths of a mile north of Halliday School. Thickness of face, 14.7 feet; cover, 7 to 20 feet over an area 2000 feet by 100 feet. Available quantity, 250,000 tons. Transportation facilities, one mile haul to Butler-Slippery Rock State Highway near Stone House.

7. Quarry of Jacob Snyder and Sullivan Estate, on the opposite side of Big Run from the C. E. Smith quarry. Thickness of face 11 feet; cover light, in some places not exceeding five feet. Available quantity, 1,500,000 tons. Transportation facilities, one mile easy haul to Butler-Slippery Rock State Highway.

Slippery Rock Township, Butler County.

8. Quarry of Ringard Graham on west side of Wolf Creek, 1¾ miles west of Slippery Rock village. Thickness of face, 16 feet; cover not exceeding 30 feet; available quantity, 1,750,000 tons; transportation facilities poor, two mile haul to Slippery Rock.

9. Quarry of G. W. Heinz on east side of Wolf Creek, 1½ miles west of Slippery Rock village. Thickness of face, 16 feet; cover not excessive. Available quantity, 500,000 tons. Transportation facilities, 1½ miles haul to Slippery Rock.

10. Quarry of David Dickey on north side of Slippery Rock Creek in southwest corner of township. Thickness of face, 16 feet; cover from 0 to 30 feet; available quantity, 100,000 tons. Transportation facilities, 1¼ miles haul to Slippery Rock-New Castle State Highway.

11. Quarry of Samuel Walker half mile southwest of Doughertys Mills. Thickness of face, 12 feet; cover from 0 to 12 feet on an area 700 feet by 100 feet extending into land of J. B. Demil. Available quantity, 70,000 tons. Transportation facilities, two mile haul to State highway.

12. Quarry of John Sanderson half a mile southeast of Doughertys Mills. Thickness of face, 11 feet; available quantity, 250,000 tons. Quarry is on the Butler-Slippery Rock State highway.

13. Quarry on properties of Sylvester Kelley and Shafer Keister, on opposite sides of Coaltown road east of Keisters. Face, 9 to 16 feet; cover, 0 to 30 feet. Available quantity, 900,000 tons. Transportation facilities, short haul to Keisters Station, on the B. & L. E. Railroad. One mile of siding on the existing grade would reach the quarries.

14. Quarry of Henry Wilson, on Branchton-Slippery Rock road midway between the two places. Thickness of face, 8 feet or more, Available quantity on area 1500 by 100 feet, 100,000 tons. Transportation facilities, 1½ mile haul to State highway.

15. Quarry of W. W. Dougherty on the north side of Slippery Rock Creek near Maniteau. Thickness of face, 18 feet; quarry face one mile long, can be developed and carried back for 100 feet or more without excessive cover. Transportation facilities lacking at present.

Parker Township, Butler County.

16. Quarry of Edwin Griffith, immediately west of Parkers Landing. Thickness of face, 10.8 feet. Present face of 70 feet can be extended in length. Entire cover from 8 to 24 feet. Available quantity, 300,000 tons. Transportation facilities, short haul to Parkers Landing or about one mile across the river to the Pennsylvania Railroad.

17. Quarry of William Parker one mile north of Parkers Landing. Thickness of face, 10 feet; present length of face 110 feet which can be extended over entire knoll without extensive stripping. Available quantity, 600,000 tons. Transportation facilities, one mile haul to Parkers Landing or to the Pennsylvania Railroad.

18. Quarry of R. B. Thomas 1½ miles west of Parkers Landing on the road along the north branch of Bear Creek. Thickness of face, 12 feet; cover can be stripped for a few yards. Available quantity uncertain. Suitable only for local roads.

Mercer Township, Butler County.

19. Quarry of George Searing just south of Harrisville. Thickness of face, 10 feet. Cover can be stripped on an area 1000 feet by 500 feet. Available quantity, 400,000 tons. Transportation facilities on the Pittsburgh-Franklin highway, two mile haul to B. & L. E. Railroad.

Marian Township, Butler County.

20. Quarry of Joseph Duffy northwest of Atwells Crossing. Thickness of face, 16 feet; present quarry face can be extended 3000 feet around brow of hill; entire cover from 8 to 16 feet. Available quantity, 600,000 tons. Transportation facilities, none at present. A siding from Hilliards Branch on the B. & L. E. Railroad, ¼ mile long involving a span across Slippery Rock Creek, and a gravity plane 750 feet long would be necessary.

Irwin Township, Venango County.

21. Quarry of J. I. Huntsberger west of Barkeyville. Thickness of face, 8.4 feet. The present face 120 feet long can be extended to 1500 feet, and quarried back for 200 feet. Available quantity, 200,000 tons.

22. Quarry of Boyd Harris, ¾ mile east of Mechanicsville. Thickness of face, 6 feet, with face not fully exposed. An area 1000 feet by 500 feet can be quarried without excessive cover. Available quantity, 250,000 tons. Transportation facilities, one-half mile haul to State highway northeast of Mechanicsville.

Clinton Township, Venango County.

23. Quarry of William Witherup one mile north of Anderson Stone House. Thickness of face, 15 feet on an area 1500 feet long and 1000 feet wide, under cover of from 10 to 20 feet. About 2,000,000 tons can be quarried. Transportation facilities, haul of 1½ miles to the Emlenton-Clintonville State highway.

24. On farms of F. Atkin, the Calvert Heirs, G. N. McFadden, W. N. Riddle and L. Scott, approximately two miles east of Clintonville. Small openings show a face 8 feet thick, and drill holes are said to have passed through 18 feet. This area is under light cover and a large quantity of good stone available on the several properties could be delivered with a comparatively short haul to the Emlenton-Clintonville State highway.

Scrub Grass Township, Venango County.

25. Quarry one mile east of Crawford Corners and 500 feet south of State Highway. Thickness of face, 9 feet or more. The present face can be developed in length to 1500 feet and quarried back 200 feet. Available quantity, 200,000 tons. Transportation facilities, close to State Highway.

AVAILABLE SITES FOR NEW QUARRIES.

Muddy Creek Township, Butler County.

1. Southside of Muddy Creek at Portersville Station. Face 12 feet or more high. Transportation facilities, Western Allegheny Branch of the B. & L. E. Railroad.

Worth Township, Butler County.

2. Three-fourths of a mile north of Portersville Station between the road running north and the creek on the east. Bed for a distance of one mile may be uncovered, under cover of 30 feet or less. Available quantity, 6,500,000 tons. Transportation facilities, siding may readily be constructed to Portersville Station, Western Allegheny Branch of the B. & L. E. Railroad.

3. On south side of Slippery Rock Creek near first bridge above confluence with Wolf Creek. Face, 9.5 feet and over; cover, 5 to 10 feet. Available quantity, 34,700 tons or more. Transportation facilities, ¼ mile haul to Slippery Rock-New Castle State highway.

4. George Weimer farm ¼ mile east of Jacksonville-Moores Corner road. Face, 15 feet; cover, 0 to 13 feet. Available quantity 380,000 tons. Transportation facilities, ¾ mile haul to Slippery Rock-New Castle State highway.

5. Near the Weimer farm on property of H. Shields. Face, possibly 18 feet; cover slight. Available quantity, 500,000 tons. Transportation facilities, ¾ mile haul to Slippery Rock-New Castle State highway.

6. On Slippery Rock-New Castle State highway just west of Moores Corners. Face, 10 feet or more; cover, 0 to 20 feet.

Clay Township, Butler County.

7. One-half mile north of Hallston on property of W. Thomas. Face, not measured; cover thin over a large area. A few rods from main line of B. & L. E. Railroad. Area should be prospected.

Slippery Rock Township, Butler County.

8. One and one-half miles east of the confluence of Wolf and Slippery Rock creeks, on north side of Slippery Rock creek on property of W. E. Robinson. Thickness of face, 16 feet; cover not exceeding 12 feet. Available quantity, 134,000 tons. Transportation facilities, 1½ mile haul to Slippery Rock-New Castle State highway.

Good quarry sites might be found at a number of places eastward and north of Slippery Rock Creek for three miles or more to quarry of Samuel Walker. Transportation facilities, however, are poor unless operations would be sufficiently extensive to justify the construction of a siding 1¾ miles long with a bridge over the creek. A vast tonnage would be available in this district on faces probably averaging 18 feet.

9. One-third mile northwest of Doughertys Mills on either side of road. Thickness of face, 20 feet; cover, 0 to 11 feet on one side and 0 to 16½ feet on the other. Available quantity, 300,000 tons. Transportation facilities, on the Butler-Slippery Rock State highway.

10. Near Adams Corners south of quarry of Climax Lime and Stone Co., along north side of run. Thickness of face, 14 feet; cover not excessive on area 200 feet by 250 feet. Available quantity 600,000 tons. Transportation facilities, siding ¼ mile long should be built to the B. & L. E. Railroad, at Wick.

Cherry Township, Butler County.

11. On west side of McMurrays Run between quarry of Branchton Limestone and Ballast Co. on the south and quarry of the Pittsburgh Limestone Co. on the north. Face, 15 feet with cover 0 to 30 feet on an area 4000 feet by 200 feet. Available quantity, 1,000,000 tons.

Transportation facilities, quarry might be worked in connection with adjoining quarries which have crushing plants and shipping facilities.

12. A short distance south of Atwells Crossing on farm of M. A. Thompson, at an elevation of 110 feet above railroad grade. Face, 15 feet with cover not excessive on an area of 9000 feet by 200 feet. Available quantity, 2,250,000 tons. Transportation facilities, a self acting incline plane 600 feet long should be constructed on short siding on the B. & L. E. Railroad.

13. One mile southeast of Bovard on properties of Joseph Hamilton, C. J. Simpson, and the Grossman Heirs, et al. Face, 15 to 18 feet; cover thin at outcrop but increases rapidly up the slopes. Face may be extended for about one mile. Transportation facilities, an abandoned branch line of the railroad passes the site.

14. East of the Rye Bread School. Thickness of face, 18 feet. A face of nearly two miles can be opened around a knoll which can be completely stripped. Available quantity very large. Transportation facilities, none, unless siding be constructed on an old grade from Branchton on the B. & L. E. Railroad, or product carried through gap to site near Atwells Crossing referred to as No. 12.

15. One mile north of Maniteau on west side of road from Maniteau to Atwells Crossing. Face, 18 feet; cover, 0 to 30 feet. Available quantity 2,000,000 tons. Transportation facilities poor at present, not near any railroad or State highway.

Parker Township, Butler County.

16. Two miles southwest of Parkers Landing on road to Bruin. Face 6 feet, cover light. Available quantity, 25,000 tons. Transportation facilities poor; available only for local improvements.

Mercer Township, Butler County.

17. East of Harrisville, between the east and west forks of McMurray Run, extending into Marian Township. Thickness of face 15 to 20 feet. Cover thin over a large area. This site seems favorable for large quarrying operations, with 10,000,000 tons available. To afford adequate transportation facilities, a spur from the B. & L. E. Railroad 2¼ miles long would be necessary. No excessive grading would be required.

Marian Township, Butler County.

18. North of Atwells Crossing on property of S. J. Black. Thickness of face 10.8 feet. A face 750 feet long can be worked to a depth of 200 feet without excessive cover. Available quantity, 200,000 tons.

Transportation facilities, road haul of about one mile to Atwells Crossing, on Hilliards Branch of the B. & L. E. Railroad.

19. Two and one-half miles west of Murrinsville on road to Harrisville on the farm of R. Gillquist. Thickness of face, 16 feet; cover, light. Available quantity, 200,000 tons. Transportation facilities good for local roads only.

Venango Township, Butler County.

20. Small quarry sites can be developed in this township for local highways. The formation is thin in most places, seldom exceeding 10 feet. It is thickest in the northeastern part of the township along the headwaters of Little Scrubgrass Creek.

Irwin Township, Venango County.

21. In the southeastern part of the township on the northwest side of Pittsburgh and Franklin Highway, a face of limestone 1500 feet long and 6 feet or more in thickness can be opened under cover not exceeding 18 feet, and will yield 100,000 tons of stone available for that highway. Other outcrops along the highway may be opened for like purpose. Over the township generally the Vanport is thin.

Scrubgrass Township, Venango County.

22. Immediately north of Anderson Stone House a face 3500 feet long with a thickness of 15 feet can be opened and quarried back for a distance of 300 feet, and would yield 1,000,000 tons. Transportation facilities, $\frac{1}{2}$ mile haul over a dirt road to Emlenton-Clintonville State highway.

STRIPPING.

In the district studied the overburden is in most places of a shaly character and easily removed, provided its depth is not great. In small quarries the cover is usually dug by hand and removed by wheel barrow or cart. This method is slow and relatively expensive. For quarrying on a large scale, light tracks, dump cars, and steam shovel, should be provided.

In most cases the character of the overburden or cover is well adapted to steam shovel work. In stripping beds where the rock surface is irregular, it is frequently necessary to follow up the steam shovel with hand shovel work, in order to keep the product clean. The operators in each instance must decide what methods will give the best results in tonnage costs.

MINING.

Usually the underground mining of rock is too expensive for road purposes, and the Vanport formation is too thin to readily adapt itself to this type of production. However, in several localities this rock is being taken out in this way. The necessary equipment for mining differs little from that for large quarries, except that apparatus must be supplied for ventilation and for keeping the mine drained. Mining is practiced in the district by driving cross entries from a main passage and mining out rooms at right angles to the cross entries, alternating on opposite sides. Where the limestone is 18 feet thick, about 12 feet can be mined, leaving 6 feet for roof. Rooms vary in width from 25 to 40 feet and pillars from 20 to 25 feet, depending upon condition of roof and nature of cover. Rooms may be from 200 to 300 feet long.

USES.

The Vanport limestone of this section is suitable in quality for

1. Road building. No other stone in northwestern Pennsylvania excels or even equals it in wearing qualities and cement value.
2. Fluxing stone. The low percentage of silica, phosphorus, and aluminum in the Vanport limestone makes it available for this purpose.
3. Sintering stone. For this purpose the stone must be broken to a $\frac{3}{4}$ inch size.
4. Cement. The Vanport being high in lime and low in silica is largely used with blast furnace slag in the manufacture of Portland cement. Limestone, to have good cement value should contain sufficient lime to bring the percentage in the mixture up to 75 per cent, should contain not more than 4 per cent magnesia, 6 per cent silica, no large amounts of aluminum or iron sulphides, and should not be too hard or too porous.
5. Lime. The Vanport is well adapted and largely used for lime, both for agricultural and commercial purposes.

Vanport limestone of Lawrence County.

By F. B. Peck.

In Lawrence and adjacent counties the Vanport limestone is remarkably presistent and rather uniform in both thickness and character. In thickness it ranges from 14 to 23 feet, with an average in the majority of localities where it was examined (at outcrops or in quarries) of 18 feet. In most places several distinct benches or subdivisions in the formation can easily be distinguished, owing to somewhat pronounced changes in the lithological and chemical character of the rock. (See figure 7) Usually the upper bench, 5 to 8 or even 12 feet thick, consists of gray, highly fossiliferous limestone, in which the bedding planes are rather widely separated and regular in character, giving this part of the formation a thick or heavy bedded appearance. Chemically it is reported to be somewhat impure, containing 70-75 per cent of carbonate of lime ($CaCO_3$), the remainder being mostly silica and alumina. This upper bench breaks with a conchoidal fracture into angular fragments, rudely equidimensional.

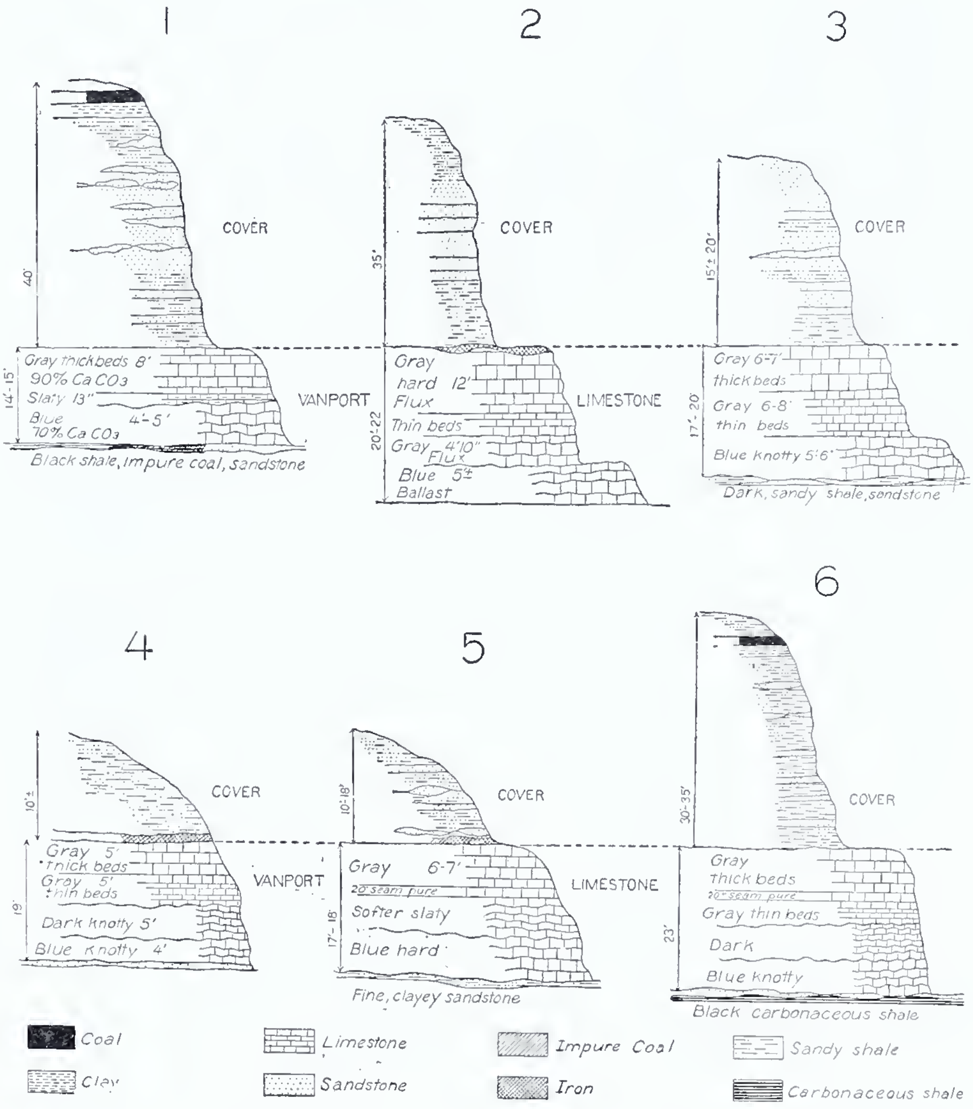


Figure 7. Cross sections of Vanport limestone quarries, Lawrence County.

1.—Lehigh Portland Cement Co., New Castle.
2.—Shenango Limestone Co., 1 mile south of New Castle.
3.—Interstate Limestone Co., 1½ miles northwest of Chewton.
4.—Duck Run Limestone Co., 3 miles north of Hazeldell.
5.—Rose Point Limestone Co., Rose Point.
6.—Clidesdale Stone Co., Ellwood City.

Below this upper bench usually occurs 2 feet of a more or less slaty variety of limestone which has a tendency to break in long flat pieces. This slaty character is exaggerated on weathering, for where the rock has been long exposed, the slaty character is clearly visible. Usually, however, where the rock is freshly broken, its slaty character is not particularly noticeable and would not detract materially from its good road building qualities.

Below this somewhat slaty horizon or bed usually comes 2 to 5 feet of purer limestone, the purest in the formation, said to contain 96 per cent $CaCO_3$. It is sometimes called the "Bull layer or bed" and sometimes goes by the name of the "20-inch seam or bed." It breaks into equidimensional fragments and has an irregular or conchoidal fracture.

Below this bench of purer limestone lies 3 to 5 feet of dark blue limestone, having a rather thin and very irregular bedding which gives the limestone a decidedly warty or knotty appearance. It is usually very hard and splintery, and breaks into irregular fragments. Chemically it is somewhat impure and is reported to average 74 to 76 per cent $CaCO_3$. The bottom layer, a foot or less in thickness, is often flinty in character and seems to be decidedly impure. It is sometimes referred to as "bottom rock."

These various horizons or benches are not always distinguishable in different quarries. Occasionally, however, the upper gray limestone with its thick regular bedding comprises nearly two-thirds of the entire thickness of the Vanport and can be quickly and easily distinguished from the blue knotty limestone below with its thin, irregular bedding. The upper gray portion is the rock best suited for flux, while the lower bench of blue limestone is less suited to that purpose and is sometimes left in the quarry floor to be quarried later for ballast or concrete. Both the gray and the blue as well as the slaty beds, are suitable for cement making, and occasionally the blue is sold as flux for open hearth furnaces.

DESCRIPTION OF INDIVIDUAL EXPOSURES.

The Vanport limestone is the only rock suitable for road metal in Lawrence County. In Beaver County it occurs too low down, i. e. too near drainage, and consequently under too heavy a cover, to be conveniently quarried. But northward in the southern part of Lawrence County it gains an elevation of 1000-1050 feet, and is far enough above drainage and near enough toward the tops of the hills to be economically stripped or mined by underground methods for flux, ballast, concreting, and lime, or cement. Northward about New Castle it gains an elevation of 1100 feet and keeps it west of New Castle at Hillville and at the Ohio State line. East of New Castle, in the eastern part of Lawrence County and the western part of

Butler County, about Rose Point, Paynes, and Portersville Station, it lingers at or near 1200 feet. Northward from these points, in Mercer County, it climbs up into the tops of the hills and attains an elevation of 1350 or 1400 feet. Across the entire width of Lawrence County, both east and west of New Castle, the limestone is found under a comparatively light cover and can therefore be economically stripped and quarried over relatively large areas. It will be noted that the large quarrying operations of Lawrence County are located east and west of New Castle. It is because the limestone in this latitude occurs well toward the tops of the hills under cover that varies from nearly zero to once, possibly twice, its own thickness and is seldom more than that. A few miles south of New Castle, as at Hazeldell and Wampum, the cover becomes so heavy as to be prohibitive for most quarrying operations and mining is resorted to as at the Crescent Portland Cement Co's. quarry immediately south of Wampum. North and northwest of New Castle, except for one large outlier in Neshannock township, the limestone has been eroded.

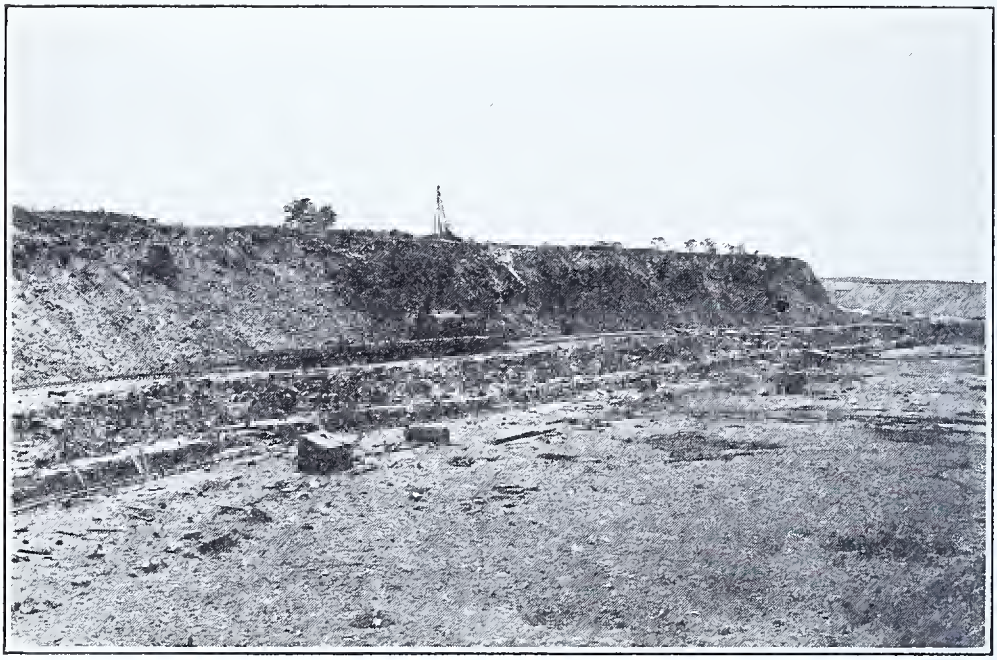
The Vanport limestone was carefully examined at more than 70 localities. Where possible, the thickness of the limestone was measured with a steel tape and a detailed examination made of the various beds to determine their suitability for road purposes.

In addition to these 70-odd localities, the limestone was inspected at numerous points along the outcrop so that over most of the county its elevation and character were determined with some accuracy.

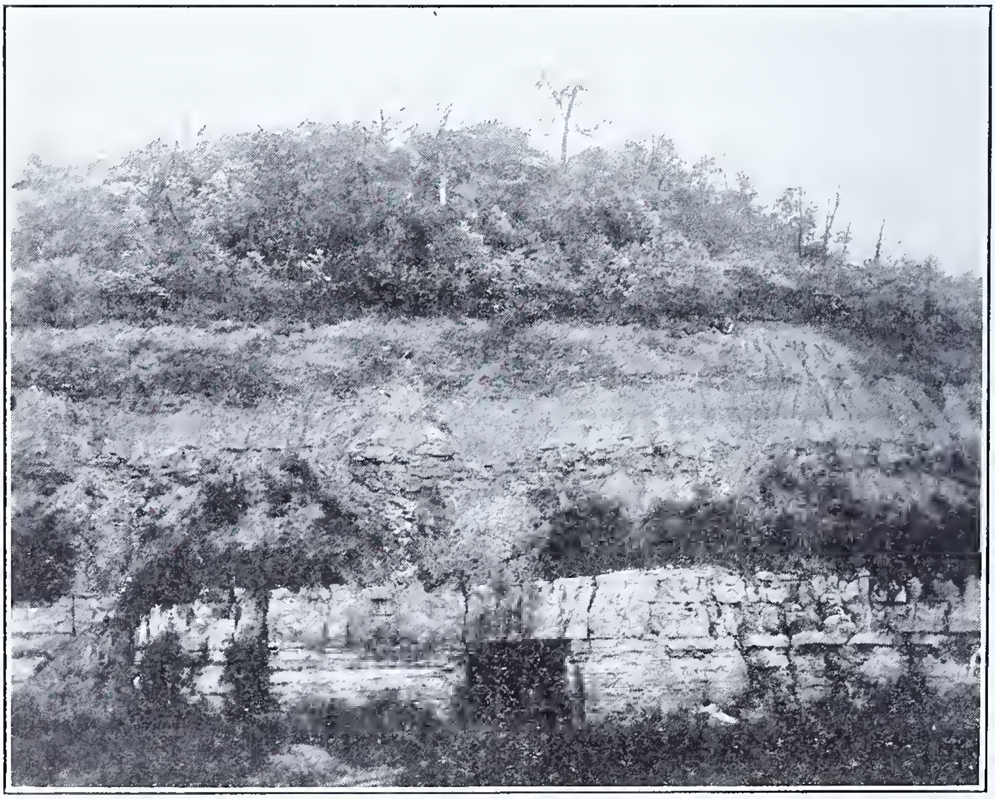
A description of a few of these localities, with observations on the character and availability of the rock, will now be given.

New Castle.—Just east of New Castle are the extensive quarries of the Lehigh Portland Cement Co. The limestone here is under a cover of sandstone and sandy shale, with a coal seam underlain by fire clay at the top, and 30-40 feet above the top of the limestone. This coal seam is probably the Lower Kittanning coal and is 20 to 30 inches thick. This shale furnishes the necessary clayey ingredient which is mixed with the limestone to form the proper mixture of raw materials necessary in the manufacture of Portland cement. Plate XIV, A, shows the heavy cover on the limestone.

The limestone is here 14 feet thick and shows the several benches or sets of beds which are rather typical of the Vanport limestone everywhere in Lawrence County. The upper bench or set of beds is gray and consists of thick or heavy beds with rather even bedding planes. The limestone is hard and breaks with an uneven fracture into angular fragments. Chemically, it is reported to have a $CaCO_3$ content of 74-76 per cent. This upper bench is 5 feet thick. The succeeding bench is also gray and hard but has a higher content of $CaCO_3$ (96 per cent). The quarrymen occasionally refer to this bed



A. Vanport limestone in north quarry of Lehigh Portland Cement Co. New Castle.



B. Vanport limestone mine, Crescent Portland Cement Co., Wampum.

as "Bull limestone." The lowest bench is darker and somewhat impure, having 70 per cent $CaCO_3$. The bedding is irregular and the rock has a warty or knotty appearance due to this irregular bedding. Its thickness is 4 to 5 feet.

Below this lowest bench comes 1 foot of black sandy shale which is followed by 1 foot of impure coal.

About 1 mile south of New Castle is the quarry of the Shenango Limestone Co. It is one of the best places in the New Castle region from which to derive an immediate and large supply of limestone for road metal. The concern is in operation and a considerable tonnage is at present being supplied for flux, ballast and roadmaking. The quarry face is 2500-3000 feet long. The limestone here is 20 to 22 feet thick and is quarried in two benches. The upper bench consists of about 12 feet of gray limestone, the lower 4 or 5 feet of which is thin bedded. This upper bench has been quarried in the past, chiefly for flux. The lower bench, which is about 5 feet thick, is blue, exhibits the usual irregular bedding of the lower part of the Vanport limestone, is hard and knotty and not suitable for flux, hence has been left in the bottom of the quarry to be quarried later from time to time for ballast or road metal.

The cover on this limestone is 34-35 feet thick at the deepest point. Toward the north end of the quarry it is much thinner, diminishing to 10 or 15 feet of disintegrated sandstone and shale, and is in places even thinner, so that there is a considerable area here that could be easily and inexpensively stripped.

All of the beds in this quarry seem of suitable character for road building.

The company is equipped with all modern appliances for quarrying on a rather large scale, including drills (both pneumatic and churn), steam shovel, and a crusher of several hundred tons daily capacity.

Three-fourths of a mile northeast of New Castle Junction, on a farm of 50 acres owned by a Mr. Cooper is an old quarry, formerly leased by the Geo. W. Johnson Limestone Co. Immediately to the south there are from 10 to 12 acres of ground underlain by the limestone, which has been thoroughly tested and said to be of good quality and thickness. In the old quarry but 8 or 10 feet of the limestone are exposed, the base of it being concealed by debris and water which has been dammed in to furnish water for stock.

Much of the adjacent territory to the north still is underlain with the limestone.

West Pittsburgh.—North of West Pittsburgh, the limestone outcrops 1040-1060 feet above sea level, and one can see 8 feet of the rock, which is not its entire thickness. There is a small opening in it.

Just east of West Pittsburgh is an old quarry that has not been in operation since 1911. The quarry face is 250-300 feet long and exposes a thickness of 20 feet of good limestone. The cover for a distance of 200 feet back from the quarry face varies from 15 to 30 feet in thickness and consists of soft disintegrated sandstone and sandy shales. The elevation of the beds here is 1060-1080 feet. One foot of the inferior iron ore occurs above the limestone. The limestone outcrops to the north along the hillside for some distance from the quarry.

Half a mile south of Union Valley an outcrop of the limestone shows a thickness of 23 feet. This is the maximum for the Vanport limestone in Lawrence County, so far as observed.

Chewton.—Half a mile northeast of Chewton are the old quarries of the Lawrence Limestone Co., previously owned and operated by the Geo. W. Johnson Limestone Co., New Castle, Pa. These quarries, which are extensive, have not been operated for 10 years and the spur from the Baltimore and Ohio R. R. has been removed. The old quarry face exposes the limestone for 1000 feet or more, the average thickness being 12 to 14 feet.

The cover, which at the quarry face is 15 to 40 feet thick, increases rapidly up the slope of the hill to 70 feet at 200 feet from the quarry face.

This rapid increase in cover was probably the reason for the abandonment of the quarry. Coal has been mined from a bed 80 to 90 feet above the limestone.

Half a mile northwest of the previous locality is another old quarry of considerable extent. The limestone here is 15 to 20 feet thick. The upper 10-12 feet has been quarried, probably for flux; much of the lower bench, 5 feet thick, which consists of hard blue limestone, has been left in the quarry floor, and would be available for road metal. This rock extends back under the old waste heaps, where it could be easily recovered. The cover over the limestone here is 25-30 feet thick and consists of thin bedded sandstone.

Half a mile east of Newport is the extensive quarry and the modern well-equipped crusher of the Interstate Limestone Co. The limestone is exposed in the quarry face for half a mile along the west slope of the hill, and has a thickness of 17-20 feet. Three benches are distinguishable, all apparently suitable for road material. The usual gray and blue varieties of limestone are typically developed.

Eastward from the northwest end of the quarry, around the end of the ridge, there seems to be a considerable acreage of good stripping ground, where the cover would be light. At the southern end of the quarry considerable rock has been stripped.

One mile north of Chewton are the extensive quarries of the Pittsburgh Limestone Co. and the Lawrence Limestone Co. The quarrying operations of the two companies have developed one continuous quarry face about 1¼ miles long. The two quarries are under one management, the Lawrence Limestone Co.

At the south end of these quarrying operations the elevation of the limestone is 1020-1040 feet; but northward it rises rapidly to 1060-1080 feet.

At the south end the limestone is 18 to 20 feet thick and consists of two benches, the upper 12 feet being gray and the lower 6 blue. At this end of the quarry for a stretch of 1500 feet along the quarry face, the rock is too highly siliceous for flux and no quarrying is in progress at present. The rock, however, is perfectly suited, as it seems, for road metal. Furthermore, it is next to the tipple where the rock is loaded into cars for transportation. There are 30 to 40 acres of ground that could easily be stripped and quarried, and hundreds of thousands of tons of rock already broken or ready to be quarried so that this place is one of the very attractive points for immediate supply. The cover along the quarry face is 20-30 feet thick and increases to 50 feet, 200 feet back from the quarry face.

At the north end of the quarry the rock is suitable for flux, the upper 12 feet of gray limestone being shipped for flux in Bessemer furnaces, while the lower 6 feet of blue rock is used in open hearth furnaces. All the rock from this part of the quarry is thus sold for flux, most of it being shipped to Sharon and East Johnstown.

Duck Run.—The quarry of the Duck Run Limestone Co., owned by the Harmony Mercantile Co., Eidenau, Pa., three-quarters of a mile south of Duck Run, is not in operation though equipped with tracks, cars, and a small crusher. The quarry face is 200-300 feet long and exposes 18-19 feet of good limestone.

The cover at the quarry face varies from 5 to 15 feet and increases to 30 feet 100 feet back from the face. Conditions for further operation here are favorable.

Wampum.—Just south of Wampum is the quarry of the Crescent Portland Cement Co. All the rock quarried is used in cement manufacture. The limestone here is 21 feet thick. The cover ranges from a few feet at the extreme northern end of the quarry to 50 or 60 feet at its deepest point about midway along the quarry face. The amount of silica and alumina in the limestone is too low for the raw mixture, so that the sandy shale that overlies the limestone is added in sufficient quantities to give the proper percentages of lime carbonate, silica and alumina to the raw material. Thus a part of the overburden is utilized in the manufacture of the cement. The cover is not stripped from the limestone, but the limestone is mined by underground methods, the upper 3 or 4 feet being left to support the roof. So far as observed, this is the only place in Lawrence County where the limestone is being taken by underground methods. The mine entry and the shale and sandstone overlying the limestone are shown in Plate XIV B.

The quarry is an extensive one, extending around the northern end of the ridge and southward along its western side. Here the cover is thin and about three-quarters of an acre of limestone has been stripped. This was originally a separate quarrying proposition.

Ellwood City.—Just south of Ellwood City, is the extensive quarry of the Clydesdale Stone Co. The limestone formation here reaches its maximum thickness so far as observed in Lawrence County, consisting of gray with underlying blue beds, which together measure 23 feet. The cover, which is 30 to 40 feet thick, consists of thin bedded shaly sandstone and greenish gray sandy shale with a seam of coal and a thick bed of clay about 30 feet above the surface of the limestone. This cover is stripped and manufactured into paving brick in the company's brick yard. The limestone is quarried, crushed and sold mostly for road building, though some of it is disposed of for flux. About 250 tons of limestone are crushed daily at this well-equipped plant. A commendable economy in the utilization of all the materials quarried, either for brick making or road material, deserves brief mention. The elevation of the limestone in this quarry is approximately 1020-1040. There is a perceptible dip to the west however, for 1 mile to the west from this point, the limestone has an elevation of 980 to 1020.

North and northwest of Hazeldell there are many outcrops of the Vanport limestone. Small quarries have been opened in several places.

On the farm of Mr. F. W. Cochran, 1½ miles west of Moravia, the Vanport outcrops in the field north and west of the house at an elevation of 1050 feet. This tract has been drilled by the Crescent Portland Cement Co. and 16 feet of limestone is reported.

On the farm of Mr. Kelso, 1 mile northwest of Moravia, the limestone outcrops again at an elevation of 1050 feet. The beds here seem to lie between 1030-1050. Northward from here on the farm of Mr. E. O. Duff, there is an exposure of 4 feet of limestone at about the same elevation.

On the farm of Mr. A. R. Bright, half a mile north of Kelso's, is an old limestone quarry, which 30 years ago was worked for flux. The quarry was an extensive one, extending to the north along the side of the hill. About 10 feet of gray rock was removed, leaving about 5 feet of blue rock in the bottom of the quarry. The total thickness is 15 feet or more. The cover at the quarry face is from 10 to

15 feet thick and consists of soft glacial debris. It slopes gently upwards to the west and 200 feet from the quarry face is but 20 or 25 feet thick.

West of New Castle near the State line, the limestone gains an elevation of 1100 feet. It maintains this elevation with surprising persistency, or rather we should say, that erosion has discovered the relatively hard, resistant Vanport limestone, which here assumes a horizontal attitude over a large area, the limestone being the controlling factor in the topography. It is a great bench-former or terrace-former wherever it gains enough elevation above drainage to influence the topography.

Hillsville.—In the region about Bessemer and Hillsville, and north from these places, the soft friable sandstones and sandy shales that form the cover of the limestone, have been nearly removed. North of the Mahoning River most of the limestone has also been removed, residual patches of it remaining in the top of the hills. The horizontality of the resistant limestone occasionally imparts a horizontality to the area which it underlies.

A mile southwest of Hillsville is a new quarry opened by the G. W. Johnson Limestone Co. The cover here is 15-20 feet thick and the limestone 15 feet thick. The limetone is being stripped and quarried by the Crucible Steel Co. 2 miles east of Hillsville. The cover here is from 10 to 20 feet thick. The quarry is known as the Midland Quarry.

Just north of the previous locality are the extensive quarries of the Union Limestone Co. The cover is 10 to 30 feet thick. The limestone averages 20 feet, the upper 15 feet of gray rock being quarried for flux, the remaining 5 feet sold for ballast.

One of the most extensive quarries in the region, owned by the G. W. Johnson Limestone Co. lies 1 mile east of Hillsville. The rock here is being quarried for flux.

One mile northwest of Hillsville are the Lake Erie Limestone Co's. quarries and nearby are the extensive operations of the Carbon Limestone Co.

Bessemer.—Quarry No. 5 of the Bessemer Limestone Co., just north of Bessemer, is equipped with 2 steam shovels for stripping and 1 for handling the rock. The cover here is glacial drift which is 10 to 25 feet thick. The glacial scratches on the surface of the limestone run S. 30° E. and are splendidly developed. The limestone is 22-23 feet thick and is being shipped for flux and ballast or road metal.

Just south of Bessemer are quarries No. 2 and No. 3 of the Bessemer Limestone Co. Here are the crusher and the washeries of the company, where the product of their quarries is prepared. The gray rock is sold as flux. The blue rock is crushed and screened to four sizes, viz, 2 inch, 1 inch, ⅝ inch, and "sand." This crushed and sized blue limestone is sold to the State Highway Department for road material.

Another quarry of the Crucible Steel Co. 1½ miles northeast of Bessemer, has been in operation for 20 years. The upper 15 feet of gray rock in this quarry is used for flux and the lower bench, 5 feet thick, is quarried for concreting and road material, some of which latter is used by the State Highway Department.

On the State line, just north of the Mahoning River, is the quarry of the Mahoning Limestone Co. This is a magnificent quarry and an extensive one. The limestone is about 18 feet thick and of the usual two varieties, gray and blue. The cover consists of glacial drift. The surface of the limestone is beautifully glaciated, the striae running S. 30° E. All of the product of this quarry is shipped for flux. This includes both the gray and the blue limestone, so that no bottom rock is left in the quarry. The crusher is located on the B. and O. R. R. south of the quarry, and prepares 1000 tons daily. A few tons of screenings from the crusher are disposed of daily for various purposes.

Robinson.—One mile east of Robinson, is a nearly level area of 100 acres or more, formerly underlain by the limestone, which here had a thin cover of rock and glacial debris. The gray limestone has been quarried from nearly all of this area, but the blue limestone was left in the quarry floor. There are places where 6 feet of blue limestone can be seen under the debris and it seems probable that the entire area is still covered with this blue rock, although this could not be positively determined.

Conditions are similar in an area about 1½ miles northeast of Robinson. Here we have what was an outlier of the Vanport limestone, under very thin cover, from which most of the gray limestone has been quarried for flux, leaving the blue rock in the bottom of the quarried area. There are from 2 to 4 feet of this blue limestone still visible over most of this tract.

Another isolated patch of the limestone, which is intact, lies 2½ miles north of Robinson. Much of this virgin patch of limestone lies on the farm of Mr. Arthur Wright. Here an opening shows 14 feet of good limestone, the upper 12 feet being gray, with 2 feet of blue rock below. On this farm 18 to 20 acres are underlain by the limestone. The adjacent farms to the northwest are in part also underlain by it.

Throughout this entire southwestern corner of Lawrence County, which is badly covered with rock debris, few exposures of Vanport limestone seem to exist, and limited time did not permit a careful search for them. In the open valley of Little Beaver Creek about Enon Valley, it apparently lies close to 1000 foot above sea.

Northward in the valley of Beaverdam Run and Honey Creek it has an elevation of 1040-1060 feet. From here it rises gently to the north.

One mile northeast of Eastbrook at an elevation of 1140-1160 the Vanport limestone outcrops along the south slope of the hill. Here on the farm of Mrs. H. M. Wilson, 166 acres are underlain by the limestone. Only 6 to 10 feet are visible, mostly gray limestone. The entire thickness could not be ascertained. The cover is very light, being only 4 to 10 feet of glacial debris.

Rose Point.—Just south of Rose Point is the quarry of the Rose Point Limestone Co. The limestone here is 18 to 22 feet thick. The upper 6 or 8 feet consists of the usual gray rock and the lower 10 to 12 feet of blue, with a so called "20-inch seam" of purer limestone between them. The lower 5 feet are extremely hard and splintery, and seem to have especially good abrasive qualities. The rock from this quarry was formerly sold as flux, but is now being quarried and burned mostly for lime, some being ground and sold to the farmers at $9.50 per ton for fertilizer. The cover here varies from a few feet to 20 feet. About 18 inches of iron ore lie between the rock cover and the limestone. The company owns a tract of 40 acres, one-half of which is still underlain by the limestone.

Adjoining this tract on the south is the farm of Mr. J. Stuart Brown, Wayne Iron Works, Pittsburgh, Pa. On this farm much mining was done for the iron ore but the limestone was left intact. The cover here on the limestone is relatively light and there are many acres of ground (20-40) that offer an especially attractive field for limestone quarrying. A spur from the Bessemer and Erie R. R. has been constructed to the quarry and lime kilns.

The limestone outcrops on the farm of Mr. Stoner three-fourths of a mile west of Rose Point, under light cover. A quarry could be opened here to advantage, in fact the rock has already been quarried in a small way and ground for fertilizer. The limestone is 1200 feet above sea.

In the eastern part of the county, near the headwaters of Jamison Run, the limestone crops in the bed of the stream.

Plaingrove.—One mile northwest of Plaingrove it outcrops on both sides of Taylor Run. The ledges are 5 to 6 feet thick but the total thickness could not be ascertained. The elevation of the limestone here is 1180-1200 feet.

One and a quarter miles northwest of the former locality, on the farm of Mr. N. A. Offett, the limestone crops out in the field southwest of the house and is being quarried for burning. Six feet of hard gray rock is exposed in a recent opening. The limestone is also quarried on the farm of Mr. T. M. Gealey immediately west of the Offett premises, but it is thin here and appears to be mostly eroded. Clay seams in the limestone are numerous. The swampy areas lie on or just beneath the limestone.

Analyses of Vanport limestone of Lawrence County.

	1	2	3	4
$CaCO_3$	94.785	94.214	93.340	95.768
$MgCO_3$	1.369	1.732	1.460	1.097
Al_2O_3	1.187	.805	1.563	.632
S.	.123	.165	.123	.088
P.	.032	.020	.047	.017
Insoluble	2.080	2.790	3.070	1.970
	99.576	99.726	99.603	99.572

1. Vanport (Ferriferous) limestone. Moffit's quarry, 2 miles north from Croton. Compact; brittle; sparkling with calcite; bluish gray and pearl gray; with irregular fracture. (MM., p. 297)
2. Vanport (Ferriferous) limestone. L. K. Shinn and Bros.' quarry, near Wampum, Big Beaver township. Compact; brittle; sparkling with calcite; bluish gray. MM., p. 297)
3. Vanport (Ferriferous) limestone. Green, Marquis and Johnson's quarries, near New Castle. Compact, brittle; sparkling with calcite; bluish gray, with irregular fracture. (MM., p. 298)
4. Vanport (Ferriferous) limestone. McCord's quarry, 3 miles northwest from Mt. Jackson, North Beaver township. Compact, brittle; sparkling with calcite; pearl gray, with irregular fracture. (MM., p. 298)

Vanport limestone of Mercer County.

The Vanport limestone has a very limited development in Mercer County. White shows several small areas in the southern part of Springfield and the southeastern part of Liberty and Pine townships with a few small outliers on the tops of the highest hills in Jackson and Worth townships. It possesses the characteristics of the same limestone as developed in Butler and Lawrence counties, described above.

Five miles east of Mercer, in Mercer County, the Vanport limestone is found in isolated patches in the tops of the hills, with an elevation to the west of 1350, but rising rather rapidly to the east and acquiring an altitude of 1395 to 1400. The rock here outcrops on both sides of the north-south highway and has been quarried for burning. Eight feet of good gray limestone are visible in the old quarry, which was operated some 40 years ago, but this is not the total thickness. One-eighth of a mile to the southwest a recent drill hole penetrated 11 feet of glacial material with 14 feet of limestone below it. This was on the farm of Mr. J. A. Barnes. The limestone here lies between 1350 and 1370 feet elevation and the cover, which is glacial debris, has an average thickness of 8 to 10 feet.

The Vanport limestone outcrops 2½ miles northeast of Grove City at an elevation of 1340 feet south of Kerr School and 3½ miles northeast of Grove City in the road south of the church at an elevation of 1350 feet. The cover at both of these places is thin and of glacial origin.

Limestones of Allegheny Group.

Lower Freeport limestone.—The Lower Freeport limestone is wanting in Mercer County as it occupies a higher horizon than any strata that are now preserved. It has not been observed in Lawrence County even though its horizon is present there. In Butler County it is developed in only a few places. Where found in the northern part of the county it is scarcely one foot thick. In the southern part of the county it has been observed in more localities. It is always more ferruginous and argillaceous than the Upper Freeport limestone which it resembles in other characteristics. In Winfield Township it is developed but is worthless because of the abundance of iron carbonate. In Butler and Summit townships it has been observed in several places and has been burned for agricultural lime. Where developed it seldom or never exceeds 3 feet in thickness.

Upper Freeport limestone.—The Upper Freeport limestone is not present in Mercer County, is developed in limited areas in Perry Township only in Lawrence County, but is found in numerous places in Butler County. In a few places in Lawrence County it is as much as 8 feet thick and has been quarried and burned for agricultural lime.

In the southeast corner of Lawrence County at an elevation of 1200 feet above tide, occur thin beds of limestone 20 to 24 inches thick, pinkish to drab or gray, having a distinctly conchoidal fracture. An attempt had been made to quarry it one mile east of Pleasant Hill. This seems to be the Freeport limestone, which here is too thin and impure to be of economic importance.

The Upper Freeport limestone is developed over the greater portion of the southern part of Butler County. It has been noted especially in Clay, Muddy Creek, Franklin, Conoquenessing, Butler, Summit, Jackson, Forward, Penn, Cranberry, Adams and Clinton townships and is fairly persistent. It averages from 2 to 5 feet in thickness. In some places it is divided into two parts by a few feet of shale. It is a fresh water limestone, compact or brecciated, high in iron. Its only use is for agricultural lime and even for that purpose it is not well suited on account of the difficulty with which the lime slakes.

Limestones of the Conemaugh Group.

The Conemaugh group is present in the southern part of Butler County where it contains the Brush Creek, Pine Creek and Ames (Crinoidal) limestone, all of which are thin, non-persistent, and of no economic importance.

ARMSTRONG AND CLARION COUNTIES.

The geology of Armstrong and Clarion counties was studied in considerable detail by the Second Geological Survey of Pennsylvania, the results of which were mainly published in Reports H5 and VV. Later the geologists of the U. S. Geological Survey re-studied most of the two counties and have described their observations in Bulletins 65 and 249 and in Folios 115, 123, 125, and 178.

In the geologic section that follows, compiled from various sources, the various members that have received names are given. These include practically all the coals and limestones but not many of the shales and sandstones that comprise the major portion of the stratigraphic column.

Although a number of limestones are given in the section and are described in the following pages, only two are of any particular importance—the Vanport and Upper Freeport. The Vanport is especially valuable as it is well adapted for use as flux, lime, cement, pulverized limestone (raw), and for the construction of hard-surfaced roads. It will become of increasing importance as transportation facilities are improved. The Upper Freeport limestone is mainly valuable for use as a fertilizer, either raw or burned to lime, and as such has long been used. The other limestones, although utilized in a few places, are of little consequence.

Generalized geologic section of Armstrong and Clarion counties.

	Feet.
Monongahela group	200±
Benwood limestone	
Sewickley coal	
Sewickley (Fishpot) limestone	
Redstone coal	
Pittsburgh sandstone	
Pittsburgh coal	
Conemaugh group	650±
Pittsburgh limestone	
Connellsville sandstone	
Morgantown sandstone	
Ames limestone	
Bakerstown coal	
Brush Creek coal	
Brush Creek limestone	
Saltsburg sandstone	
Mahoning sandstone	
Allegheny formation	360
Upper Freeport coal	
Upper Freeport limestone	
Upper Freeport sandstone	
Lower Freport coal	
Lower Freeport limestone	
Lower Freeport sandstone	
Upper Kittanning coal	
Middle Kittanning coal	
Lower Kittanning coal	
Kittanning sandstone	
Vanport (Ferriferous) limestone	
Clarion coal	
Clarion sandstone	
Craigsville coal	
Brookville coal	
Brookville fire clay	

	Feet
Pottsville series	140
Homewood sandstone	
Mercer coals and shales	
Mercer limestone	
Conoquenessing sandstone	
Pocono series	345+
Burgoon (Mountain or Big Injun) sandstone	
Cuyahoga (Meadville) shales	

Distribution of the Geological Formations.

The oldest strata exposed belong to the Pocono series. These are sandstones and shales and can be seen along Clarion River east of Clarion, along Redbank Creek west of New Bethlehem, and along the Allegheny River between Phillipston and Templeton. Some of the earlier workers believed that the Mauch Chunk series was also present in the region but it is now believed to be absent due to an erosional unconformity. The Pottsville strata composed mainly of sandstones but with some shales and a single bed of impure limestone are exposed in almost all the larger stream valleys of Clarion County and in the major stream valleys of Armstrong south as far as Mahoning Creek with a small outlier along the South Fork of Pine Creek in the vicinity of Oscar. The Allegheny group forms almost all the uplands of Clarion County and the upper valley slopes in the northern part and the valley bottoms in the southern part of Armstrong County. The Conemaugh caps some of the highest hills in the southern part of Clarion County and constitutes the major portion of the uplands in Armstrong County. The Monongahela group has a very limited development in the uplands in the southeastern part of Armstrong County bordering Indiana County.

Descriptions of Individual Limestones.

Mercer limestones.—The lowest limestone member in these counties is the Mercer. It has been recognized near McCrea Furnace in Armstrong County where it consists of 6 to 10 feet of sandy limestone lying about 140 feet below the Vanport limestone. It is of no value.

Vanport limestone.—As in other adjoining counties the Vanport is the most valuable limestone developed in Armstrong and Clarion counties. In the former it has a wide development but less in the latter.

The Vanport limestone is a gray rock containing many marine fossils, such as brachiopods, crinoid stems, corals, and mollusca. In many places it is distinctly separable into two members, the upper, gnarly or shaly and fairly impure with the lower, massively bedded, hard, and pure. The lower member is generally twice or three times as thick as the upper. The lower portion seldom contains less than 95 per cent calcium carbonate. The impurities are almost equally divided between magnesium carbonate, silica, iron oxide, and aluminum oxide. It is an excellent stone for flux and has been both quarried and mined extensively for this purpose for local use and for the Pittsburgh region where the stone is accessible for railroad transportation. As it generally outcrops along steepsided valleys it is seldom possible to obtain large quantities by open quarry methods and consequently underground mining has been necessary.

The stone is also well adapted for the manufacture of Portland cement although at present it is not used in these counties. Locally the Vanport is quarried by the farmers to be burned for agricultural lime or to be pulverized and used in the raw state. The better layers almost invariably meet the specifications of the State Highway Department and the stone is increasingly utilized for the construction of good roads.

The Vanport limestone is almost invariably overlain by an iron ore, originally iron carbonate but in many places altered to limonite or hematite. Although this is in most places no more than 10 to 14 inches, rarely 20 to 24 inches thick, it was at one time mined in many places and smelted in local furnaces in which the limestone was used for flux. The presence of this ore in association with the limestone was responsible for the old name, Ferriferous limestone.

The Vanport varies in thickness considerably. For miles it may be regular and then suddenly decrease or entirely disappear within a very short distance. This change has been attributed to original differences in deposition, to subsequent removal before the overlying beds were deposited, or to underground solution at a later period. The prevalent view seems to be the first but probably the other explanations are also correct for some localities.

Vanport limestone of Armstrong County.

The Vanport limestone is extensively developed in the northern part of Armstrong County. It presents the best exposures along the Allegheny River from Foxburg to Kittanning and extending up the valleys of the tributary streams from 1 to 4 miles. It also outcrops on the west side of the Allegheny in the valley of Buffalo Creek in the vicinity of Buffalo Mills and West Winfield, and on the east side of the river in the valleys of Redbank and Mahoning Creeks to the eastern boundaries of the county, and is exposed along Scrubgrass Creek southeast of Gaheenville, along the North Fork of Pine Creek in the vicinity of Slabtown, along the south fork of Pine Creek from Pine Furnace to Echo, along Cowanshannock Creek in the vicinity of Stone House and Greendale, at two points along Crooked Creek near Girty, and possibly along Kiskiminitas River a short distance southeast of Cherry Lane although it is probable that the ledge termed Vanport is actually Freeport.

In the summer of 1919 the writer and A. H. Fretz collected much information concerning the Vanport limestone for the State Highway Department and the following locality descriptions are based on this work.

The Vanport limestone outcrops near the top of the Allegheny River bluffs in the extreme northwestern part of the county to a point opposite Foxburg. It is practically continuous and averages about 10 feet in thickness.

Between East Brady and Kaylor, the Pittsburgh Limestone Co. has quarried the Vanport limestone along Sugar Creek and Cove Run for flux. The limestone removed ranges from 11⅙ to 13⅙ feet. A somewhat gnarly limestone about 2 feet thick is left as the roof. Above this is about 6 inches of iron ore overlain by black shale. In 1917 the company was producing from 2500 to 4000 tons of stone per day. Osgood steam shovels were used in part although most of the stone was shoveled by hand.

Along Huling Run the Vanport outcrops almost to Sterrett but has been quarried only to a slight extent. It is about 20 feet thick.

Up the hill from Rimerton the Vanport has been quarried along the outcrop for about a quarter of a mile for agricultural lime. It is about 8 feet thick and of good quality.

Along Buffalo Creek there are many openings. At Nichola the Punxsutawney Iron Co. formerly worked a quarry for flux. South of Buffalo mills for a distance of about 2 miles the Pittsburgh Limestone Co. has operated a series of mines to obtain flux. The limestone is from 15 to 18 feet thick.

In the vicinity of West Winfield, there are several limestone mines worked by the Pittsburgh Sand Co., the Pennsylvania Clay Products Co., and the Winfield Sand Co. for flux. The limestone is about 20 feet thick. The iron ore above the limestone was formerly mined here and smelted nearby.

Opposite Kittanning the Vanport is about 10 feet thick and of good quality. It has been quarried to a limited extent.

The Vanport is well developed along Redbank Creek. Near its mouth the outcrops are about 200 feet above the stream but descend almost to the stream level near New Bethlehem. In the vicinity of South Bethlehem it is about 6 feet thick and has been quarried for lime in several places.

The valley of Mahoning Creek contains the most favorable localities within Armstrong County for quarrying the Vanport limestone. It outcrops continuously on both sides of the main valley and along the tributary valleys. It is well exposed in numerous places along the Pittsburgh and Shawmut R. R. near Putneyville, where it averages about 6 feet in thickness. Numerous quarries have been opened to obtain stone for agricultural lime and in the past for flux for local blast furnaces.

About 1 mile northeast of Grays Eddy a number of farmers have quarried the limestone for local use. It is about 8 feet thick.

The Templeton Limestone Co. has mined the Vanport limestone for open hearth furnace flux about 1 mile south of Templeton. The opening is about 30 feet above the railroad tracks. The stone removed ranges from 7 to 8 feet and about 1 foot of less pure gnarly stone is left as a supporting roof. Iron ore with a thickness of about 1 foot overlies the limestone. The entries and rooms are 25 feet wide and timbering is not required except in a few places where the roof limestone falls. The rock is crushed and sized in a revolving screen to 1/4 inch, 1½ inches, and 2¼ inches. The finest is sold for farm use and the balance for flux.

East and southeast of Putneyville are a number of small quarries worked for local farm use. One mile east of McCrea's Furnace, J. W. Best has a large quarry where the Vanport is 7 feet thick.

Near Slabtown the Vanport is exposed close to the level of the water in North Fork of Pine creek where it has been quarried on both sides of the stream. It is about 10 feet thick and is massively bedded and of good quality.

Although the Vanport outcrops for about 5 miles along the South Fork of Pine Creek it has been quarried in few places. At Pine Furnace it is quarried and pulverized for farm use. It is about 7 feet thick, the lower 5½ feet massive and of good quality.

In the vicinity of Stone House along Cowanshannock Creek the Vanport is about 8 feet thick. When visited plans were being formed to open a quarry to obtain stone to be pulverized for agricultural use.

Vanport limestone of Clarion County.

The Vanport limestone is exposed in the valley of almost every stream south of a line passing through Henderson, Mechanicsville, Shamburg, Canoe Ripple, and New Salem. It is not quite continuous although nearly so. In the western part of the area near the Allegheny River and the lower part of the Clarion River it is from 10 to 20 feet thick, elsewhere it averages from 6 to 8 feet.

Typical section of Vanport limestone.

	Ft.	in.
Overlying iron ore		
Thin bedded limestone	2	3
Shaly limestone	0	6
Thick bedded limestone	4	3
Underlying clay and coaly shale		

Detailed information is wanting concerning the quarries but there are many places where it has been utilized for the soils, for flux when the local iron ores were mined and smelted in the region, and in recent years for macadamized roads.

Lower Freeport limestone.—The lower Freeport limestone is of no value in these counties. It has been recognized on Myers Hill, about 3 miles southeast of Sligo, and on Squirrel Hill in Porter Township, Clarion County. In Armstrong County it has been described as occurring north of Garrett Run where it is developed as a ferruginous limestone about 2 feet thick. Elsewhere it is probably absent.

Upper Freeport limestone.—The Upper Freeport limestone, although less persistent than the Vanport, is developed rather extensively throughout Armstrong and the southern part of Clarion County. It is a dove-colored or buff compact limestone that breaks with a prominent conchoidal fracture and contains no marine fossils. A few minute supposedly fresh water molluscan shells, have been found in a few localities. This limestone has been quarried in scores of places for agricultural lime and for pulverizing for use in its raw state as a soil fertilizer. Locally it was at one time used for flux. A small quantity has been used in highway construction although most of it is too soft for this use.

Upper Freeport limestone of Armstrong County.

In the study of Armstrong County limestone suitable for highway purposes made by the writer and A. H. Fretz considerable detailed information was collected regarding the Upper Freeport limestone upon which the following brief descriptions are based.

The upper Freeport limestone occurs in the northwestern part of Armstrong County high in the stream bluffs but is of little value. It has been quarried for lime east of Sherrett. In the Buffalo Creek basin it is not continuous and is of little importance. Along Glade Run it is fairly continuous and has been quarried in several places to be burned for lime for local farm use. In the extreme southwest corner of East Franklin Township two quarries expose 4 to 5 feet of fair stone. One mile east along Glade Run the Upper Freeport has been quarried for many years. It is there 6 feet thick.

In the vicinity of Ford City the Upper Freeport limestone has been more extensively quarried than in any other part of the region. On the west side of the river, almost opposite Ford City, a quarry was long worked for flux for shipment to Pittsburgh. The ledge is said to be 18 feet thick but only 5 feet are now exposed.

Half a mile northeast of Ford City the Upper Freeport was formerly burned for flux but in recent years has been used as pulverized stone. The section exposed is as follows;

Section of Upper Freeport limestone near Ford City.

	Ft.	in.
Surface soil	4-5	0
Top limestone, thin bedded	5	0
Shale	1	0
Siliceous limestone, massive	2	0
Blue compact massive limestone	3-4	0
Drab shale	2	0
Irregular limestone breaking into rounded boulders (nigger head)	3	0
Shale	0	6
Heavy compact limestone (Glass rock)	2½-3	0
Shale	0	6
Bottom limestone, irregular	3-4	0

Up the stream for half a mile above this quarry the same limestone has been quarried in several places for open heap burning for local farm use.

At Garrett Run the Upper Freeport limestone has been quarried for lime. The product is sold as hydrated lime for fertilizing purposes. The section is as follows:

Section of Upper Freeport limestone at Garrett Run.

	Ft.	in.
Sandstone and shale	12	0
Upper Freeport Coal	3-4	0
White clay	3	6
Shale	4	6
Limestone	2	0
Shale	0	6
Limestone	0	10
Black shale	3	0
Thick bedded limestone	8	0
Shale	?	

In the north part of Armstrong County east of the Allegheny River the Upper Freeport is lacking in many places but near the tops of the hills it is frequently observed. It generally is 2 to 6 feet thick and is locally quarried. The most extensive quarry is about 2½ miles southeast of Belknap where a great deal of stone has been obtained by the farmers in the vicinity. The thickness exposed is about 14 feet including about 4 feet of interbedded shale.

On the south side of Cowanshannock Creek about 3½ miles east of Kittanning there are several quarries exposing about 12 feet of limestone and interbedded shale.

One mile south of Oscar a large amount of Upper Freeport limestone has been quarried and hauled by the farmers to their farms for burning for agricultural lime. The section exposed is as follows:

Section of Upper Freeport limestone 1 mile south of Oscar.

	Ft.	in.
Soil and sandstone	3	6
Clay containing 6-inch coal seam	5	0
Limestone	2	6
Shale	0	6
Limestone	1	0
Shale	2	0
Limestone	2	0
Fire clay	0	4
Limestone (exposed)	5	0

One mile south of Greendale similar limestone has long been quarried for the same purpose.

Upper Freeport limestone of Clarion County.

In Clarion County the Upper Freeport is present only in the southern quarter of the county where it is found near the tops of a few of the highest elevations. It has been definitely recognized 3 miles southwest of Limestone near the top of a 1660-foot hill, on Squirrel Hill and Myers Hill, in the vicinity of New Athens and Sandy Hollow and thence northwestward to Concord Church. It has been quarried to a slight extent in a few places.

Limestones of the Conemaugh group.—Of the limestones of the Conemaugh group developed in the region there is little to be said as they are very local, thin, and generally decidely impure. In a very few places a thin limestone associated with the Brush Creek coal is thought to be the Brush Creek limestone. It is of no value. The Ames limestone has been definitely recognized near the tops of three hills in North Buffalo Township, Armstrong County. On the farm of J. M. Rea, 1½ miles northwest of Slate Lick it is exposed as a greenish gray rock containing abundant crinoid stems and other fossils. It is 2 to 3 feet thick. Similar exposures were seen 1½ miles to the east and 1 mile northeast of Sistersville. So far as known it has never been quarried. A somewhat similar limestone about 1 foot thick has been observed east of the Allegheny River in Armstrong County which perhaps should be correlated with the Ames.

In the vicinity of Olivet, in the southeastern part of Armstrong County, the Pittsburgh limestone is developed as a fairly pure, compact, moderately heavy bedded and brittle limestone about 5 feet thick. It was formerly quarried for lime in a few places.

Limestones of the Monongahela group.—The Benwood limestone is developed in the area underlain by the Monongahela strata on Elders Ridge in the southeastern portion of Armstrong County and the southwestern part of Indiana County. So far as known all of the Benwood limestone present is in Indiana County where there is a thickness of about 25 feet of interbedded limestones and shales. The limestone has been quarried and burned for lime.

Analyses of Carboniferous limestones.

Nos. 1-14, Armstrong County; 15-21, Clarion County.

	1	2a	2b	2c	3	4	5
$CaCO_3$	84.857	96.453	93.214	93.571	88.839	94.928	94.642
$MgCO_3$	1.868	1.445	2.065	1.324	1.513	1.210	1.574
$Al_2O_3+Fe_2O_3$	2.568	.964	1.340	1.207	2.557	1.246	1.182
SiO_2	9.520	.830	2.200	3.170	5.030	1.920	1.850
P	.024	.007	.004	.029	.021	.018	.012

	6a	6b	6c	7	8	9	10	11	12
$CaCO_3$	89.303	82.589	89.857	53.750	64.160	96.007	94.721	95.567	94.185
$MgCO_3$	1.900	5.751	2.898	9.989	1.838	1.498	1.044	1.422	1.483
$Al_2O_3+Fe_2O_3$	2.002	3.367	1.860	7.730	7.450	1.462	1.383	.930	2.089
SiO_2	4.830	7.310	4.520	23.840	22.280	.790	2.300	2.110	2.100
P	.021	.063	.017	.131	.305	.034	.047	.035	.031

1. Freeport Upper limestone. From W. R. Hamilton's land near the coal mine, 1½ miles north from Putneyville. Fine grained, tough; dark gray. (M3, p. 83).

2. Freeport Upper limestone. Mehaffey & McGill's quarry, Armstrong County. Quarry is ¾ mile east from Logansport. (a) Top layer is fine-grained and brittle; dark pearl gray. (b) Second layer is fine grained; tough; dark pearl gray. (c) Bottom layer is very compact and fine-grained; hard and tough; light pearl gray with conchoidal fracture (M3, p. 83).

3. Freeport Upper limestone. John Reefer's quarry, Armstrong County, 3 miles southwest of Rural Village. Fine grained; tough; mottled with calcite; dark gray; fracture conchoidal. (M3, p. 84).

4. Freeport Upper limestone. Wm. Marshall's quarry, 1 mile east of Dayton. Fine grained; tough; mottled with calcite; dark gray.

5. Freeport Upper limestone. S. Monroe's quarry, Armstrong County, 2 miles southwest of Slate Lick. Fine grained; tough; dark pearl gray. (M3, p. 84).

6. Freeport Upper limestone. A. J. Dull & Co., Armstrong County. Quarries in the ravine of Fort Run, near Manorville. (a) upper layer very compact and fine grained; dark pearl gray, with conchoidal fracture. (b) Second layer is fine-grained; hard and tough; somewhat argillaceous; dark pearl gray, with conchoidal fracture, small crystals of pyrite throughout the specimen. (c) Third layer is very compact and fine-grained; slightly mottled with calcite; pearl gray, with conchoidal fracture. (M3, p. 84).

7. Johnstown cement. M. Davis' limestone, Armstrong County, one-half mile southeast of Cochran's mills. Outcrop specimen. Rather coarse grained; exceedingly hard and tough; bluish gray. (M3, p. 85).

8. Johnstown cement. George S. Putney's limestone at Putneyville, Armstrong County. Rather coarse-grained; hard and tough; bluish gray; irregularly stained with carbonaceous matter. (M3, p 85).

9. Vanport limestone. Stewardson furnace limestone, Armstrong County, one mile east of mouth of Mahoning Creek, in Madison township. F. B. and A. Laughlin. Fine grained; full of fossil casts; pearl gray; with conchoidal fracture. (M3, pp. 85-86.

10. Vanport limestone. J. A. Colwell's quarry, Armstrong County, ¼ mile northwest from Mahoning furnace. Rather compact and fine-grained; full of fossil casts; bluish gray; with conchoidal fracture. (M3, pp. 85-86).

11. Vanport limestone. Ross Reynolds' limestone, Armstrong County, one-half mile north from Kittanning. Fine-grained, fossiliferous; mottled with calcite; rather tough; light pearl gray. (M3, pp. 85-86).

12. Vanport limestone. P. George, 2 miles west from South Bend, Armstrong County. Fine grained; fossiliferous; mottled with calcite; dark gray. (M3, p. 86).

Nos. 1-14, Armstrong County; 15-21 Clarion County—Concluded

	13	14	15	16	17	18	19	20	21
$CaCO_3$	93.292	93.246	93.803	82.678	82.000	95.232	95.532	95.196	[illegible]
$MgCO_3$	.968	1.740	2.270	8.248	6.311	.407	.930	1.265	1.202
$Al_2O_3 + Fe_2O_3$	1.713	1.667	.765	1.365	2.736	1.310	1.050	1.529	.867
SiO_2	3.220	3.420	1.800	5.320	7.940	2.190	1.960	1.780	1.110
P	.047	.032	.008	.022	.015	.061	.070	.081	.023

13. Vanport limestone. P. Graff, near Buffalo Mills. Armstrong County. Fine grained; brittle; more or less stained with ferric oxide; fracture rough somewhat conchoidal; color, dark gray. (M3, p. 86).
14. Vanport limestone. J. C. Rhea, one mile west of Greendale. Armstrong County. Rather coarse grained; fossiliferous; brittle; bluish gray. (M3, p. 86).
15. Freeport Upper limestone. At New Athens, Madison township. Clarion County. Rather fine-grained; mottled and seamed with calcite; dark gray. (M3, pp. 86-87).
16. Freeport Upper limestone. Reichert's quarry, Perry township, Clarion County. Rather fine-grained; mottled with calcite; dark pearl gray. (M3, pp. 86-87).
17. Freeport Lower limestone. 3 miles northeast from Reimersburg, Toby township, Clarion County. Exceedingly hard and tough; mottled and stained with ferric oxide; color, generally bluish gray. (M3, pp. 86-87).
18. Vanport limestone. On Long Run, Porter township, Clarion County. Bed five feet to six feet thick, with nine inches carbonate ore overlying. Brittle; more or less stained with ferric oxide; generally pearl gray. (M3, p. 87).
19. Vanport limestone. Hindman's quarry, Clarion township, Clarion County. Fine grained; mottled with calcite; rather brittle; bluish gray. (M3, p. 87).
20. Vanport limestone. Sligo furnace, Piney township, Clarion County. Fine-grained; rather tough, stained with ferric oxide; light bluish gray. (M3, p. 87).
21. Vanport limestone. Barger quarry, Perry township, Clarion County. Rather coarse-grained; mottled with calcite; bluish gray. (M3, p. 87).

INDIANA AND CAMBRIA COUNTIES.

Indiana and Cambria counties do not contain much limestone although a few of the limestones named in the stratigraphic column given below are locally well developed and economically are of considerable importance. The major portion of the strata exposed at the surface consists of shales.

The Second Geological Survey of Pennsylvania first studied the geology of these counties in detail and in Reports HH and HHHH there are many local descriptions of the limestones of these counties. The U. S. Geological Survey has re-mapped the larger portion of the region and has published maps and descriptions in Folios 102, 110, 123, 133, 174, and 189 and in Bulletins 65 and 249.

General geologic section of Indiana and Cambria counties.

	Feet
Pennsylvanian.	
Monongahela group	200±
Benwood limestone	
Sewickley coal	
Redstone coal	
Pittsburgh sandstone	
Pittsburgh coal	
Conemaugh group	700±
Pittsburgh limestone	
Connellsville sandstone	
Morgantown sandstone	
Elk Lick coal	
Elk Lick limestone	
Ames (Crinoidal) limestone	
Saltsburg sandstone	
Gallitzin coal	
Mahoning sandstone	

	Feet
Allegheny group	300±
Upper Freeport coal	
Upper Freeport limestone	
Bolivar fire clay	
Butler sandstone	
Lower Freeport coal	
Lower Freeport limestone	
Upper Kittanning coal	
Johnstown (Cement) limestone	
Middle Kittanning coal	
Lower Kittanning coal	
Vanport (Ferriferous) limestone	
Clarion coal	
Clarion sandstone	
Brookville coal	
Pottsville series	130±
Homewood sandstone	
Mercer coal	
Mercer shale	
Conoquenessing sandstone	
Mississippian	
Mauch Chunk series	200±
Pocono series	1100
Loyalhanna limestone	
Burgoon sandstone	
Patton shale	
Devonian	
Catskill group	400±

Distribution of the Geological Formations.

The lowest strata in Indiana and Cambria counties belong to the Catskill group and are exposed along the Conemaugh River just southeast of the junction of Ind'ana, Cambria and Westmoreland counties. The Pocono, Mauch Chunk and Pottsville series are exposed along the eastern portions of Cambria County and in small areas, where the northeast trending anticlines, Chestnut Ridge in particular, have been cut by the large streams. The Allegheny is somewhat more widespread in the same areas and in addition is present in most of the major stream valleys of the counties. The Conemaugh strata form the surface rocks of nearly all the uplands and the Monongahela beds cap the tops of only a few hills in the extreme western and southern parts of Indiana County.

Descriptions of Individual Limestones.

Loyalhanna (Siliceous) limestone.—The following descriptions of the only occurrences of this limestone are abstracted from Folio 174 of the U. S. Geological Survey:

"The Loyalhanna limestone member is exposed in three places in these counties, all in the valley of Conemaugh and Little Conemaugh rivers and all associated with structural uplifts. The easternmost exposure is at the viaduct between South Fork and Mineral Point; here, though the base was not determined with certainty, at least 43 to 45 feet of limestone is exposed. From this place it may be traced westward to Mineral Point. The next exposure downstream is at the beginning of the long, straight northwestward stretch of the river in the southwestern part of Cambria County, and the third is near the mouth of Findley Run in the southeastern corner of Indiana County.

"This member of the Pocono is sharply differentiated from the underlying members of the Pocono and from the overlying Mauch Chunk shale by its peculiar lithologic characteristics. It consists of layers in which silica predominates alternating with those in which calcareous material is in excess. The calcareous part weathers more rapidly and leaves the siliceous layers in relief. This unequal weathering in conjunction with the cross-bedded character of the rock gives it a highly distinctive appearance, which is well brought out in the exposure near Mineral Point. At one place near the mouth of Findley Run the Loyalhanna limestone is separated into two parts by a thin layer of red shale near its middle. The member is often referred to as the "Siliceous" limestone, but it is more appropriate to regard it as a calcareous sandstone, as the siliceous portion is far in excess of the calcareous. In deference to general usage, however, it will be called a limestone. The name Loyalhanna is derived from the exposure of the member along the gorge in which Loyalhanna Creek flows across Chestnut Ridge in Westmoreland County. In the reports of the Second Geological Survey of Pennsylvania it was regarded as part of the overlying Mauch Chunk, but it merges gradually into the underlying Burgoon sandstone member and is now regarded as forming the top of the Pocono formation.

"This siliceous limestone is quarried and split into paving blocks, which give satisfaction. The crushed material is also used for ballast in railroad beds. For both uses it is well adapted, as the calcareous portion of the rock on solution and recrystallization tends to bind the fragments solidly together and yet leaves sufficient space between them to allow the free circulation of water.

"The siliceous limestone exposed near the viaduct between Mineral Point and South Fork has also been quarried for paving blocks."

Vanport limestone.—So far as known the Vanport limestone has been observed at only two places in Indiana County and nowhere in Cambria County. One locality is where Yellow Creek cuts through Chestnut Ridge a few miles southeast of Indiana. Fragments of limestone have been noted there. The other locality is described by Platt[72] as follows:

"The Ferriferous Limestone is quarried on the property of Mr. Isaac Simpson one half mile south of Richmond. It is of a very dark color, very rich in carbonate of lime and highly fossiliferous. Its thickness here has not yet been definitely ascertained, but four feet of excellent stone in one solid band have already been exposed. The deposit is overlaid by a thick stratum of dark fire clay shale. A specimen of the rock from Mr. Simpson's quarry was analyzed by Mr. McCreath with the following results:

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[72] Pa. Second Geol. Survey, Rept. H 4. (p. 264).

Carbonate of lime	92.857
Carbonate of magnesia	1.589
Oxide of iron and alumina	2.030
Sulphur	.187
Phosphorus	.035
Insoluble residue	2.090

"The same limestone occurs still further south, on the property of Mr. Jeffries, its outcrop also ranging through the fields to the east of Mr. Simpson's house."

In addition to these exposures, it has been noted in some borings but in most places it is unquestionably absent.

Johnstown (Cement) limestone.—The Johnstown limestone, formerly known as the Johnstown cement bed, is particularly developed in the vicinity of Johnstown where it was at one time used in the manufacture of cement. It is described in the Johnstown Folio (No. 174) of the U. S. Geol. Survey as follows:

> "The limestone occuring below the Upper Kittanning or "cement" coal is commonly known as the "Johnstown cement bed." It is best developed along Stony Creek and may be seen to advantage on the Baltimore and Ohio Railroad north of Kring station. It is here 6 feet thick and is separated from the coal by about 8 to 12 inches of shale. Along the spur track leading from the north end of the Baltimore and Ohio tunnel to the mine of the Valley Coal and Stone Company it is also conspicuous, but slightly thinner. The bed is nearly 3½ feet thick near Conemaugh station and nearly 5 feet thick in the section along the Pennsylvania Railroad to the west near Johnstown station. To the east on Little Conemaugh River it is exposed just at the northwest apex of the first big meander. It must be thick in all the intermediate territory. Its outcrop along Stony Creek near the Rolling Mill mine of the Cambria Steel Company is also conspicuous. Northwest of Johnstown near the old Cambria furnace and at the east base of Laurel Hill it outcrops and shows just above the waters of Laurel Run. Here it is a bluish limestone with some streaks of calcite. It is present but not very thick near South Fork, and is also reported near Scalp Level."

It seems to be extremely irregular in its distribution indicating non-deposition over many areas. It is described (Report H4) as present in many places in Indiana County, especially in the extreme southern and northern portions where it is 4 to 5 feet thick in certain localities and has been quarried for agricultural lime. There is some doubt as to whether all the limestones there described, really belong to this horizon, consequently it seems best to omit these descriptions. The writer was not able to study the region in the course of this investigation.

Analyses of the Johnstown limestone.[73]

	1	2	3	4
Carbonate of lime	36.214	58.750	78.768	34.301
Carbonate of magnesia	16.883	16.005	2.421	21.670
Oxide of iron and alumina	----------	7.380	3.540	----------
Carbonate of iron	8.078	----------	----------	8.700
Alumina	4.360	----------	----------	3.390
Sulphur	.056	.041	.097	----------
Bisulphide of iron	----------	----------	----------	1.268
Phosphorus	.056	.085	.018	.0 9
Insoluble residue	32.790	15.060	13.790	27.873

1. A. Gorman's quarry, two miles southwest from Smithport, Indiana County. Upper portion of deposit. See HHHH, p. 221. Hard and tough, with rough irregular fracture and pearl gray color. Emits a strong argillaceous odor when breathed upon.
2. A. Gorman's quarry, two miles southwest from Smithport, Indiana Co. Lower portion of deposit. Hard and tough, with irregular fracture and bluish gray color. Emits a strong argillaceous odor when breathed upon.
3. Tyhawk's quarry, one mile east from Black Lick station, Indiana Co. From main bench
4. A. J. Hawes' quarry at Johnstown, Cambria Co. See HH, p. 153. Hard and brittle; of deposit. See HHHHH, p. 190. Compact; bluish gray, with irregular fracture. bluish gray; shows considerable pyrites, and emits a strong argillaceous odor when breathed upon."

Lower Freeport limestone.—Several thin limestones are associated with the Freeport coals in Indiana and Cambria counties so that it is not easy to determine their exact correlation. Below the Lower Freeport coal there is exposed, at different places, rather impure limestone that is supposed to be the Lower Freeport. There are several exposures along Stony Creek near Moxhom where it varies from 1½ to 4 feet in thickness. In a few places both in Indiana and Cambria counties this limestone has been quarried for local farm use.

Analyses of Lower Freeport limestone.[74]

	1	2
Carbonate of lime	88.232	82.321
Carbonate of magnesia	1.371	8.021
Oxide of iron and alumina	1.960	2.630
Sulphur	.048	.102
Phosphorus	.017	.017
Insoluble residue	8.210	5.502

1. S. Palmer's quarry, three quarters of a mile west north-west of Decker's Point, Indiana Co. See Report HHHH, p. 228. Irregularly seamed with white crystalline carbonate of lime; exceedingly brittle, with rough irregular fracture and bluish gray color.
2. P. Brown's quarry, four and one half miles east north-east from Blairsville, on Cambria and Indiana pike, Indiana Co. Compact, brittle; bluish gray, with irregular fracture."

Upper Freeport limestone.—The Upper Freeport limestone occurring between the Upper and Lower Freeport coals has been noted in scores of places throughout these two counties yet it is more apt to be missing. However, it is more extensively developed than the Lower Freeport. It is an impure, compact, dove-colored, freshwater limestone suitable for agricultural lime and has been quarried on a small scale for this purpose by the farmers in many localities where it is sufficiently thick. It varies in thickness from 0 to 10 feet and is generally interbedded with shales.

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[73] Pennsylvania Second Geological Survey, Rept. MM., (pp. 294-295).
[74] Pennsylvania Second Geological Survey, Rept. MM., (pp. 293-294).

In U. S. G. S. Folio 174 (p. 6) it is described as follows:

"In the region near South Fork the Upper Freeport limestone member appears in the section. A short distance east of Ehrenfeld it is well exposed in some recent excavations made along the Pennsylvania Railroad. It ranges from 1½ to 3 feet in thickness. It is gray in color and very irregularly bedded. Its relation to the overlying Upper Freeport coal is indicated in the following section:

Section showing Upper Freeport coal and Upper Freeport limestone member at Ehrenfeld.

	Ft.	in.
Shale, blue, with alternating layers of fine grained sandstone	20	0
Sandstone (lower part of Mahoning member)	20	0
Coal, 1 foot 11½ inches Bone, 2 inches Coal, 1 foot 8 inches (Upper Freeport)	3	9½
Clay, lower foot containing limestone nodules	2	0
Limestone, irregularly bedded (Upper Freeport member)	1½-3	0
Fire clay in places	1 plus	0
Shale	15	0

It has been quarried for agricultural lime in several places in Green and Cherryhill townships, Indiana Co. as well as elsewhere.

Ames (Crinoidal) limestone.—The Ames limestone is present in both Indiana and Cambria counties but so far as known is of no economic value. Rarely is it observed to contain more than a foot of limestone that is pure enough to be of use. A good description of this member is the following taken from Folio 189 of the U. S. Geol. Survey, page 6.

"Associated with the uppermost red shale, but everywhere above it, is a fossiliferous limestone or in places a highly calcareous dark shale crowded with marine or brackish-water fossils. This is the Ames limestone member, formerly known as the "Crinoidal" limestone. It is of interest and significance as marking one of the most extensive incursions of the sea into the northern Appalachian coal field. It is known throughout a wide area in southwestern Pennsylvania, southwestern Ohio, northeastern Kentucky, and western West Virginia.

"The best-known development of the Ames member in the region is in a cut of the Cambria & Clearfield division of the Pennsylvania Railroad three-fourths of a mile north of Bradley Junction, where the following section was measured:

Section north of Bradley Junction.

	Ft.	in.
Morgantown sandstone member	30	0
Ames limestone member:		
Shale, black, carbonaceous and calcareous, with fossil shells	4	0
Limestone, dark, earthy, with fossil shells	0	4
Shale carbonaceous, full of *Cordaites* leaves (Harlem coal)	1	0
Shale, dark green	10	0

"On the road about midway between Dysart and St. Augustine a coal bed has been opened at this horizon. Above the coal are indications of rotten limestone—the Ames member—and close below the coal is a comparatively pure limestone with *Spirorbis* underlain by a thick bed of red clay. The red shale and limestone with *Spirorbis* show in the road 2 miles north of the southwest corner of White Township and half a mile east of its west boundary."

Elk Lick and Pittsburgh limestones.—In the upper part of the Conemaugh group in Indiana and Cambria Counties there are occasional limestone lentils of no particular value as they are almost everywhere too thin to quarry. Some of these have been thought to represent the Elk Lick and Pittsburgh members. About three-fourths mile northwest of Rico, Indiana County, a limestone supposed to be the Elk Lick has been quarried locally.

Benwood limestone.—Capping some of the highest hills in the vicinity of Elders Ridge, Indiana County, there are limestones and interbedded shales aggregating about 25 feet thick. At times these limestones that are easily quarried, have been used by the farmers for agricultural lime. The limestones are non-fossiliferous, gray, compact and fairly pure. The lime made from them is said to be very satisfactory.

Additional analyses of Carboniferous limestones in Indiana and Cambria counties.

	1	2	3	4	5	6	7	8
$CaCO_3$	82.768	87.868	79.821	54.768	72.264	89.821	84.407	84.125
$MgCO_3$	2.875	1.733	3.601	8.627	6.493	1.801	2.800	5.198
$Al_2O_3+Fe_2O_3$	2.830	.135	3.020	6.930	4.190	1.700	2.120	3.220
S	.156	.106	.117	.112	.068	.133	.188	.073
P	.011	.050	.018	.017	.029	.027	.018	.014
Insoluble	10.327	7.360	12.160	27.230	14.980	5.430	9.150	6.021

1. Pittsburgh limestone. A. H. Fulton's quarry, at West Lebanon. Generally compact and brittle; with irregular fracture and bluish gray color. Seamed with bluish black limestone (MM, p. 289).
2. Pittsburgh limestone. Lemont Furnace quarry, 3 miles N. E. of Uniontown. Comparatively soft and brittle; very irregular fracture and bluish gray color. (MM, p. 290).
3. Sewickley limestone. Robert Smith's quarry at Smith's station, 2 miles N. E. from Blairsville, (See Rept. HHHHH, p. 159). Compact, brittle, sparkling with calcite; bluish gray, with irregular fracture. More or less stained with iron oxide. (MM, p. 288).
4. Freeport Upper limestone. G. Livengood's quarry, 3 miles east southeast from Blairsville. Compact, brittle: bluish gray, with irregular fracture; sparkles with calcite. Specimen more or less stained with iron oxide, emits a strong argillaceous odor when breathed upon. (MM, p. 292).
5. Freeport Upper limestone. D. R. Griffith's quarry, 1½ miles north northeast from Homer. Compact, brittle; dark bluish gray, with irregular fracture. Emits a strong argillaceous odor when breathed upon. (MM, p. 292).
6. Freeport Upper limestone. S. C. Hazlett's quarry, 2 miles south of Jacksonville. Compact, brittle, bluish gray, with sub-conchoidal fracture. (MM, p. 292).
7. Freeport Upper limestone. Groft Brothers' quarry, 1 mile east of Chambersville. See Rept. HHHH p. 254. Compact, brittle, dark bluish gray, with irregular fracture, (MM, p. 292).
8. Freeport Upper limestone. Rev. S. Brown's quarry, 1½ miles southwest from Five Points. Compact, brittle; sparkles with calcite: bluish gray, with subconchoidal fracture. (MM, p. 292).

JEFFERSON AND CLEARFIELD COUNTIES.

The only limestones of Jefferson and Clearfield counties of any importance are contained in the Allegheny group and in order of age are the Vanport (Ferriferous), Johnstown, Lower Freeport, and Upper Freeport. In addition a few unidentified limestones of the Conemaugh formation have been noted in Henderson Township, Jefferson County, and may be present in some other regions. Of the limestones that are developed all are of less importance than the same members in the nearby counties lying to the south and southwest. Lithologically the strata are similar except in general they are somewhat more impure in Jefferson and Clearfield as well as thinner. Many brief notes concerning these limestones are contained in Reports H, H6 and H7 of the Second Geological Survey of Pennsylvania.

Vanport (Ferriferous) limestone.—So far as positively known the Vanport limestone is not present in Clearfield County. In Jefferson County it is a persistent stratum developed extensively in the Red Bank Creek drainage basin, outcropping in the valleys of almost all the streams that go to form Red Bank Creek. It is therefore widespread throughout the major portion of the county, being entirely absent only in the northwestern and southeastern portions.

The Vanport limestone in Jefferson County is much less valuable than in Armstrong, Clarion and Butler counties. In many places it passes into a cherty limestone and then into a sandstone. It contains many fossils, especially crinoid stems. It is gray in color and when freshly broken presents a coarse and uneven surface. It is in most cases overlain by the so-called "Buhrstone" iron ore, which is seldom more than 1 foot thick.

The Vanport in Jefferson County ranges in thickness from 0 to about 6 feet but probably averages 4 to 5 feet in all places where it has been developed. Throughout the county generally it is the limestone that has been most extensively quarried but everywhere in a small way for local agricultural lime. The analyses on a later page show the chemical composition of the better grade stone.

Johnstown limestone (cement bed).—The Johnstown limestone, formerly widely known as the Johnstown cement bed, is rather widely developed in both Jefferson and Clearfield counties. Where present it is generally from 1½ to 2½ feet thick and is rather impure. It is dark bluish-gray to light brown, somewhat fossiliferous, hard and tough and breaks with an irregular fracture. In a very few places it has been quarried and burned for agricultural lime but the large percentage of impurities almost everywhere render it of very little value.

Lower Freeport limestone.—The Lower Freeport limestone lies a few feet below the Lower Freeport coal. It is poorly developed in Jefferson County, there being only a few places where it attains a thickness of 2 feet. In Clearfield County, however, it is thicker than the Upper Freeport and locally is from 6 to 8 feet thick although ordinarily from 2 to 4 feet. It has been utilized for agricultural lime in many sections of Clearfield County and a few in Jefferson County. It is a dark gray or bluish gray stone when fresh, but weathers to a light yellow color. It is non-fossiliferous, compact, crystalline and breaks with a conchoidal fracture.

Upper Freeport limestone.—The Upper Freeport limestone has a limited development in these counties. It is thickest in a narrow belt in southwestern Jefferson County between Perryville and Worthville. In Clearfield County it is rarely present. Its position is a few feet below the Upper Freeport coal. In the vicinity of Perryville it is about 10 feet thick including some interbedded shale. Certain layers are fairly pure and yield a good grade of lime whereas others are quite impure. In a few places this member is 15 feet thick although within a few miles it may be no more than 3 or 4 feet, the ordinary thickness.

In physical and chemical composition it varies widely as the analyses given below indicate. Except locally it possesses little or no value.

Limestones of the Conemaugh group.—In Henderson township, Jefferson County, especially near Stump Creek, there are several limestones developed within the Conemaugh group. Although they are thin and fairly impure they have been quarried locally to a small extent.

Analyses of Carboniferous limestones of Jefferson and Clearfield counties.

	1a	1b	2	3	4a	4b	5	6	7
$CaCO_3$	92.500	75.357	77.143	89.107	48.571	90.000	91.875	88.928	87.035
$MgCO_3$	2.497	9.330	4.691	1.611	23.762	2.800	2.421	1.589	1.558
Al_2O_3 Fe_2O_3	1.530	4.230	3.790	2.140	7.250	1.285	1.312	1.740	2.170
SiO_2	2.390	9.780	11.780	6.170	16.660	3.480	3.130	6.770	8.400
P.	.023	.017	.073	.024	.032	.011	.012	.023	.057

1. (a) Property of James Smith, 2 miles northeast from Big Run, Jefferson County. In Lower Barren measures, 200 feet to 225 feet above Freeport Upper coal. Rather coarse grained, brittle, bluish gray. (M3, pp. 87-88).
   (b) Same as above, but 125 feet to 150 feet above Freeport Upper coal. Fine grained; rather hard and tough; pearl gray. (M3, pp. 87-88).
2. Jacob Smith, 2 miles north from Big Run, Jefferson County. 150 feet to 175 feet above Freeport upper coal. Fine grained rather brittle; with conchoidal fracture; irregularly seamed with calcite; dark bluish gray. (M3, pp. 87-88).
3. Freeport Upper limestone. N. B Lane's property, Jefferson County, 1 mile southeast from Brockwayville. Fine grained; brittle; sparkles with calcite; generally pearl gray (M3, p. 88).
4. Freeport Upper limestone. John Iler's Property, 1 mile N. W. from Perrysville, Jefferson County. (a) Upper bench. Hard and tough; appearance sandy; fracture, irregular; color, light pearl gray (b) Lower bench (?) Rather fine-grained; comparatively brittle; mottled with calcite; bluish gray. (M3, p. 88).
5. Freeport limestone. From property of D. Hopkins, 2 miles northwest from Frostburg, Jefferson County. Very fine-grained and brittle; mottled with calcite; pearl gray. (M3, pp. 88-89).
6. Freeport limestone. From property of A. Huffman, 2 miles northeast from Northville, Jefferson County. Fine-grained; brittle; mottled with calcite, pearly gray. (M3, pp. 88-89).
7. Freeport Lower limestone. N. B. Lane's property, one mile southeast from Brockwayville, Jefferson County. Fine-grained; hard and brittle; brownish gray. (M3, pp. 88-89).

	8	9	10	11	12	13	14	15	16	17
$CaCO_3$	92.857	51.410	82.393	94.392	93.643	96.428	96.578	39.428	93.810	91.880
$MgCO_3$	1.680	3.962	1.891	1.702	1.816	.908	.832	1.816	1.710	1.892
$Al_2O_3+Fe_2O_3$	2.320	7.790	4.653	1.315	1.310	.990	.780	4.760		
SiO_2	2.070			1.910	2.040	1.300	1.280	51.450	2.070	2.770
S.									.053	.135
P.	.019	.033	.300	.031	.030	.034	.037	.041	.008	.031
Insoluble		33.900	8.020							

8. Freeport Lower limestone. From Evans Round Top, one-half mile east from Corsica, Jefferson County Fine-grained; hard and brittle; brownish gray. (M3, pp. 88-89).

9. Johnstown cement bed. N. B. Lane's property, one mile southeast from Brockwayville, Jefferson County. Hard and tough; argillaceous; more or less stained with iron oxide; color, generally dark gray. The ignited "insoluble residue" contains; silica, 27.570; Alumina, 4.800; Sesquioxide of iron, trace; lime, trace; magnesia, .245 (J. M. S.) (M3, p. 89).

10. Johnstown cement bed. John Iler's property, one mile northwest from Perrysville, Jefferson County. Rather hard and tough; fracture, irregular, rough; dark bluish gray. (M3, p. 89).

11. Vanport limestone. C. Bovaird, 3 miles northwest of Brockwayville, Jefferson County. Fine grained: brittle; pearl gray. (M3, pp. 89-90).

12. Vanport limestone. From property of William Hanna, 2 miles northeast from Spraukle's mills. Jefferson County. Hard and tough; fine grained, full of fossil easts; dark bluish gray. (M3, pp. 89-90).

13. Vanport limestone. From property of A. Enty, one-half mile southeast from Worthville, Jefferson County. Fine-grained; brittle; fossiliferous; light bluish gray. (M3, pp. 89-90).

14. Vanport limestone. Samuel Shield's property, one mile north from Downlingville. Jefferson County. Rather fine-grained; fossiliferous, sparkles with calcite; pearl gray. (M3, p. 90).

15. Near Frost's house, four miles east from Brookville, on Ridgeway road, Jefferson County. Appearance sandy; exceedingly hard and tough; fracture, slightly conchoidal; color, bluish gray. (M3. p. 90).

16. Caldwell's Opening, 1 mile west of Glenn Hope, Clearfield County. Limestone hard, compact, and of a bluish gray color. (M, p. 76).

17. Owen's Opening, on Clearfield Creek, 1 mile east of Clearfield, Clearfield County. Limestone, highly crystalline of a deep blue color. (M, p. 77).

BLAIR AND CENTRE COUNTIES.

The Carboniferous strata are present as a narrow band extending along the northwestern part of Blair County and occupying the same position but constituting a wider area in Centre County. The Pocono and Mauch Chunk series are exposed near the top of the Allegheny Front, and the Pottsville and coal measures lie to the westward.

The Carboniferous limestones of these counties are of little consequence. Although thin, impure, and discontinuous, it is possible that they might be utilized more were it not for the close proximity of Cambro-Ordovician and Helderberg limestones of excellent quality and in large quantity in other parts of the counties.

The Carboniferous limestones that have been noted in these counties are the Loyalhanna (Siliceous) of the Pocono series, and in the Allegheny group the Vanport (Ferriferous), Johnstown, Lower Freeport, and Upper Freeport. All are sparingly developed unless it be the Loyalhanna which is more of a calcareous sandstone than a siliceous limestone. In the vicinity of Allegrippus it is well exposed with a thickness of 40 feet. It could probably be found in various other places to the northeast if search were made for it.

Of the Coal Measures limestones, the Lower Freeport is best developed in the Snow Shoe Basin where it is impure and never more than 3 feet thick. The other limestones have been noted in a few localities but none of them is of any economic importance.

ERIE AND CRAWFORD COUNTIES.

The Carboniferous limestones of Erie and Crawford counties are of little importance, yet, in the absence of any better limestones in the region, they have been utilized in a few townships by the farmers as a source of agricultural lime. The only limestone members are the Cassewago, Lower Meadville, and Upper Meadville of the Pocono (possibly Mauch Chunk) series. Practically all the available information concerning them is found in Report Q4 of the Second Geological Survey of Pennsylvania. The Cassewago limestone has been noted in Concord Township, Erie County, and in Hayfield and Venango townships, Crawford County. It varies from 1 to 2 feet in thickness. It has been used to a very limited extent for lime.

The Lower Meadville limestone is probably absent in Erie County but is widespread throughout Crawford County where it seldom exceeds 2 feet in thickness. It is high in silica, some specimens containing as much as 60 per cent although it is believed that in most places it does not have more than 20 per cent. It is useless as a flux but fairly satisfactory for agricultural lime. Exceptionally, it is pure enough for plastering lime.

The Upper Meadville limestone is rather widespread in Crawford County. Unlike the other two limestones it is well filled with fossil remains. It seldom exceeds 1 foot in thickness and is practically useless.

FOREST, ELK AND CAMERON COUNTIES.

The counties of Forest, Elk and Cameron are grouped in this discussion although actually no limestones of any value are known to occur in either Forest or Cameron. Elk County is better provided with limestones as it contains a number in the Allegheny formation—the Vanport, Johnstown, Lower Freeport, and Upper Freeport—and a few lenses in the Pocono formation. Of the Allegheny limestone members represented, no one of them is as important in Elk County as in some of the counties lying to the south and southwest.

No recent limestone investigations have been made in this region so that most of the data has had to be compiled from reports of the Second Geological Survey of Pennsylvania, especially Report R2.

Benezette limestone.—A layer of limestone about 1 foot thick, seen in a few places in Jones Township, has been called the Benezette limestone. It is impure and worthless.

Vanport limestone.—The Vanport (Ferriferous) is the principal limestone of Elk County. It is present in three synclinal basins that extend in a northeast direction across the county.

The most northwesterly of these areas in which the Vanport outcrops extends through Jones, Ridgway, and Spring Creek townships. In the vicinity of Rasselas, the Vanport is fairly well developed and has been quarried for lime. It is, however, not continuous and in places the horizon where it should occur contains a layer of carbonate of iron ore or calcareous chert. It is present in only a few places in Ridgway and Spring Creek townships. The best exposure in the county is near Rasselas where the following section was exposed in a quarry.[75]

Section of Vanport limestone near Rasselas.

	Ft.	in.
Gray slate	?	
Rotten greenish gray limestone	3	0
Gray shale	8	0
Iron ore	1	0
Hard massive blue limestone	7	11
Slate	1	6
Coal	1	4

The second basin containing the Vanport is in Benzinger, Horton and Fox townships and extends from West Creek in a southwesterly direction through St. Marys, Kersey, and Brockport. In this belt the Vanport outcrops in small areas near St. Marys but in the valley of Toby Run is fairly continuous. Where well developed it has a thickness of 6 to 10 feet. It has been quarried locally for lime.

The third basin where the Vanport is preserved is in Jay Township in the vicinity of Caledonia. In this section it is thinner and more impure than in the other areas. It is high in silica and iron.

Johnstown limestone (cement bed).—An impure limestone from 2 to 6 feet thick lying about midway between the Vanport and Lower Freeport limestones in Horton, Fox and Jay townships has been supposed to be the Johnstown limestone. It is of little or no value.

Lower and Upper Freeport limestones.—In Horton and Fox townships both the Lower and Upper Freeport limestones have been identified in a few localities. The Lower is about 4 feet thick and the Upper about 2 feet. In all probability some stone from these two members has been used locally although they are of very limited value.

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[75] Ashburner, C. A., Pennsylvania Geol. Surv. Rept. RR, p. 73.

Analyses of Carboniferous limestones of Forest and Elk counties.

	1	2	3	4	5	6
Carbonate of lime	40.642	80.357	81.875	69.357	57.321	86.910
Carbonate of magnesia	1.172	1.619	7.189	9.308	8.854	6.659
Oxide of iron and alumina	2.120	3.610	2.750	4.835	7.940	2.205
Phosphorus	.018	.086	.036	.077	.038	.017
Siliceous matter	55.160	12.290	6.540	13.680	21.250	2,390

	7	8	9a	9b	9c	10a
Carbonate of lime	86.214	91.785	27.857	54.553	49.732	94.357
Carbonate of magnesia	1.785	1.808	.983	1.135	1.331	1.634
Oxide of iron and alumina	2.610	1.710	3.830	3.030	3.650	1.638
Phosphorus	.050	.032	.062	.104	.238	.031
Siliceous matter	7.370	3.370	61.670	38.950	41.690	1.630

	10b	11	12	13	14
Carbonate of lime	94.107	50.357	85.714	36.785	76.143
Carbonate of magnesia	1.369	2.467	1.171	1.408	1.740
Oxide of iron and alumnia	1.626	7.040	3.422	10.070	3.680
Phosphorus	.063	.054	.069	---------	---------
Siliceous matter	2.200	36.860	8.390	50.670	15.980

1. Tionesta limestone. Kelley's quarry, four miles east from Tionesta, on Tionesta creek, Forest County. Saddle Bags tract. Two to three feet thick. Coarse grained; appearance, sandy; exceedingly hard and tough; bluish gray. (M3, p. 90).

2. Freeport Upper limestone. From J. S. Hyde's farm, Horton township, Elk County. One mile south from Brandy Camp P. O., on Brandy Camp creek. Rather coarse grained and brittle; fracture irregular; light bluish gray. (M3, p. 91).

3. Freeport Lower limestone. J. S. Chamberlain's farm, Horton township, Elk County; Brandy Camp creek, one and one-half miles south from Brandy Camp P. O. "K limestone." Rather fine grained and brittle, with conchoidal fracture; light bluish gray. (M3, p. 91).

4. Freeport Lower limestone. J. C. McAllister's farm, Horton township, Elk County; Brandy Camp P. O. "K limestone of Horton township." Rather fine grained and brittle; fracture, sub-conchoidal; color, pearl gray. (M3, p. 91).

5. Freeport Lower limestone. T. Fox's farm, Horton township; Mead run, three fourths mile north from Brockport, "K limestone." Fine grained and brittle; fracture, sub-conchoidal; bluish gray. (M3, p. 91).

6. Vanport limestone. G. W. Winslow's farm, two miles northeast from Benezette, Elk County. Ten feet thick. Rather coarse grained; brittle; mottled with calcite and more or less stained with ferric oxide. Color, generally pearl gray. (M3, p. 91).

7. Vanport limestone. One mile east from J. S. Chamberlain's farm, from branch of Toby creek, Fox township, Elk County. Very fine grained and brittle; fracture, sub-conchoidal; dark bluish gray. (M3, pp. 91-92).

8. Vanport limestone. Brandy Camp P. O., Horton township, Elk County. Rather coarse grained; brittle; mottled with calcite; bluish gray. (M3, pp. 91-92).

9. Vanport limestone. From Oyster's quarry, Brockport, Horton township, Elk County. 7 feet more or less, thick. (a) Top stratum, appearance shaly; fossiliferous; comparatively soft; bluish black. (b) Middle stratum. Fine-grained; brittle; argillaceous; dark blue. (c) Bottom stratum. Appearance shaly; fossiliferous; bluish black. (M3, p. 92).

10. Vanport limestone. Gen. Kane's quarry, Jones township; Johnson Run coal basin; four miles northeast from Wilcox. (a) Upper bed. Fine grained and very brittle; more or less stained with iron oxide; reddish gray. (b) Lower bed. Rather fine-grained; brittle; somewhat mottled with calcite; dark-bluish gray. (M3, pp. 92-93).

11. Johnstown cement bed. J. C. McAllister's farm, Horton township, Elk County. Brandy Camp P. O. .Appearance sandy; rather coarse-grained; very hard and tough; light-bluish gray. (M3, pp. 92-93).

12. Clermont limestone. At Kyler's Corners, Fox township, Elk County. On east side of Little Toby Creek. Very fine-grained; brittle; fracture conchoidal; color, bluish gray. (M3, pp. 92-93).

13. Benezette Upper limestone. On Caledonia road, one mile west from Benezette, Elk County. Pocono. 7 feet thick. Appearance very sandy and coarse-grained; fossiliferous; light bluish gray generally. (M3, p. 93).

14. Benezette Middle limestone. On Caledonia road, one mile west from Benezette, Elk County. Pocono. 7 feet thick. Appearance rather shaly; very brittle; fossiliferous; dark-bluish gray. (M3, p. 93).

WARREN AND McKEAN COUNTIES

There is little need to more than mention Warren County in this report as it is not known to contain any limestones that can be used. In a few shale and sandstone strata the fossil shells are so abundant that there is an appreciable content of calcium carbonate but not sufficient to justify designating them as limestones.

McKean County is but little better provided with limestones. The Lower Meadville (Marvin Creek) limestone of the Pocono formation is a very sandy limestone that has been reported in many places throughout the county with a thickness up to 5 feet. So far as known it has never been used on account of its impurities. The Vanport (Ferriferous, Clermont) limestone is sparingly developed in the south central part of the county in the vicinity of Clermont where it consists of a bluish gray highly siliceous limestone from 6 to 8 feet thick. To a very limited extent it has been quarried and burned for lime but its poor quality would prevent its extensive use for this purpose.

POTTER, CLINTON, AND SULLIVAN COUNTIES.

There are no Carboniferous limestones of any importance in Potter, Clinton, Lycoming, or Sullivan counties. Here and there a few impure limestone lenses have been noted but they are rare. In Sullivan County a sandy limestone of the Pocono formation, with a maximum thickness of about 12 feet has been burned for lime to a limited extent and similar limestones, although thinner, have been noted in the same formation near Lock Haven, Clinton County, and near Coudersport, Potter County.

Lesley[75*] describes some siliceous limestones (Loyalhanna?) northeast of Coyan Station, Lycoming Co., that may be of some value for agricultural lime.

ANTHRACITE REGIONS.

In striking contrast to the bituminous coal region in the development of interbedded limestones are the anthracite districts of the State. Occasional beds containing a small amount of calcareous material have been noted but true limestones are extremely rare.

The only place where these limestones have ever been used, so far as known, is near Wilkes-Barre where it is said that at one time a siliceous limestone from 12 to 15 inches in thickness was quarried for agricultural lime[76] Two and possibly three other thin limestones have been observed in the same region. None of them is of any consequence.

[75*] Pennsylvania Second Geol. Survey, Summary Final Report, vol. 3, pt. I, pp. 1672, 1789-1791. 1801-1805.

[76] C. A. Ashburner: Pennsylvania Second Geol. Survey An. Rept., 1885, pp. 437-458, 1886. Report on the Wyoming Valley Limestone-Beds.

SUMMARY OF PRINCIPAL CARBONIFEROUS LIMESTONES OF PENNSYLVANIA.

Permian System.

Greene group:

- Windy Gap limestone.
  - Greene Co. 8 to 10 feet. Lime.
- Nineveh limestone.
  - Greene Co. 5 to 10 feet. Lime.
- Washington Co. Lenses containing some massive beds. Road metal.
- Claysville limestone
  - Washington Co. 6 to 8 feet. Lime, road metal
- Prosperity limestone
  - Washington Co. 10 to 12 feet. Lime.
- Donley limestone
  - Washington Co. 6 feet. Road metal.

Washington group:

- Upper Washington limestone
  - Fayette Co. Thin, unimportant.
  - Greene Co. 4 to 15 feet. Road metal, lime
  - Washington Co. 4 to 36 feet. Road metal, lime
- Jollytown limestone
  - Greene Co. 5 feet. Of little value
  - Washington Co. Thin, unimportant.
- Middle Washington limestone.
  - Greene Co.
  - Washington Co. 10 to 30 feet. Road metal, lime.
- Blacksville limestone
  - Greene Co. 3 feet, not important.
  - Washington Co. 3 to 5 feet, unimportant.
- Lower Washington limestone.
  - Fayette Co. Thin, unimportant.
  - Greene Co. 4 feet, of little value.
  - Washington Co. 30 feet. Road metal, lime.
- Calvin (Colvin's) Run limestone.
  - Allegheny Co. Locally developed, thin, unimportant.
  - Greene Co. 3 feet, of little value.
  - Washington Co. Thin, unimportant.
  - Westmoreland Co. Thin, unimportant.
- Mount Morris limestone.
  - Allegheny Co. Thin, unimportant.
  - Greene Co. 1 to 2 feet, non-persistent, of little value.
  - Washington Co. Thin, unimportant.
  - Westmoreland Co. Thin, unimportant.

Pennsylvanian System.

Monongahela group:

- Waynesburg limestone.
  - Allegheny Co. 1½ feet, unimportant.
  - Fayette Co. 8 to 35 feet. Lime
  - Greene Co. 10 feet. Lime.
  - Washington Co. 4 to 20 feet. Locally important.
  - Westmoreland Co. 8 to 35 feet. Lime.

Pennsylvanian System—Continued.

- Uniontown limestone.
  - Allegheny Co. Variable. Lime.
  - Fayette Co. 10 feet. Flux, lime, road metal.
  - Butler Co. 0-22 feet. Flux, lime, road metal.
  - Washington Co. 30 to 50 feet. Lime, flux, road metal.
  - Westmoreland Co. 10 feet. Flux, lime, road metal.

Benwood (Great) limestone.

- Bulger (Upper Benwood) limestone.
- Dinsmore (Lower Benwood) limestone.
  - Allegheny Co. 150 feet, valuable. Lime, road metal.
  - Armstrong Co. 25 feet. Lime.
  - Fayette Co. 85 feet. Lime, road metal.
  - Greene Co. 150 feet thick (maximum) variable composition. Lime.
  - Indiana Co. 25 feet. Lime.
  - Washington Co. Variable. Lime.
  - Westmoreland Co. 85 feet. Lime, road metal.
- Fishpot (Sewickley) limestone.
  - Allegheny Co. Thin, impure, unimportant.
  - Fayette Co. 0 to 35 feet. Lime, flux.
  - Somerset Co. Limited distribution, unimportant.
  - Washington Co. Discontinuous, thin, unimportant.
  - Westmoreland Co., 0 to 35 feet. Lime, flux.
- Redstone limestone.
  - Allegheny Co. Thin, impure, unimportant.
  - Fayette Co. 10 to 20 feet. Lime, flux.
  - Somerset Co. Thin, unimportant.
  - Washington Co. Thin lenses of limestones and shales, impure. Lime.
  - Westmoreland Co. 10 to 20 feet. Lime, flux.

Conemaugh group:

- Undifferentiated limestones (Jefferson Co.)
- Upper Pittsburgh limestone.
  - Allegheny Co. Variable. Lime.
  - Beaver Co. Variable. Lime.
- Pittsburgh limestone.
  - Armstrong Co. 5 feet. Lime.
  - Cambria Co. Thin, unimportant.
  - Indiana Co. Thin, unimportant.
  - Westmoreland Co. Thin, unimportant.
- Lower Pittsburgh limestone.
  - Allegheny Co. Variable. Some good for lime.
  - Beaver Co. Variable. Some good for lime.
  - Somerset Co. Thin, unimportant.
  - Washington Co. Thin, of little value.
- Little Clarksburg limestone.
  - Washington Co. Thin, of little value.
- Clarksburg limestone.
  - Allegheny Co. Thin, unimportant.
  - Beaver Co. Thin, unimportant.
  - Somerset Co. Discontinuous. Lime.
  - Westmoreland Co. Thin, unimportant.

Pennsylvanian System—Continued.
  Elk Lick (Barton) limestone.
    Allegheny Co. Thin, unimportant.
    Beaver Co. Thin, unimportant.
    Cambria Co. Thin, unimportant.
    Indiana Co. Thin. Lime.
    Somerset Co. 3 to 11 feet. Promising.
    Westmoreland Co. Thin, unimportant.
  Berlin limestone.
    Somerset Co. Lack of information.
  Coleman limestone.
    Somerset Co. Lack of information.
  Philson limestone.
    Somerset Co. Thin, unimportant.
  Ames limestone.
    Allegheny Co. 6 to 30 inches. Impure. Lime.
    Armstrong Co. 2 to 3 feet. Impure, unimportant.
    Beaver Co. 6 to 30 inches. Impure. Lime.
    Butler Co. Thin, unimportant.
    Cambria Co. 4 feet. Impure.
    Fayette Co. 4 feet. Unimportant.
    Indiana Co. 4 feet. Impure.
    Washington Co. 2 to 8 feet. Unimportant.
    Westmoreland Co. 4 feet. Unimportant.
  Pine Creek (Upper Cambridge) limestone.
    Allegheny Co. Thin, unimportant.
    Beaver Co. Thin, unimportant.
    Butler Co. Thin, unimportant.
    Westmoreland Co. Thin, unimportant.
  Brush Creek (Lower Cambridge) limestone.
    Allegheny Co. Thin, unimportant.
    Armstrong Co. Thin, unimportant.
    Beaver Co. Thin, unimportant.
    Butler Co. Thin, unimportant.
    Westmoreland Co. Thin, unimportant.

Allegheny group:

  Upper Freeport limestone.
    Armstrong Co. Variable thickness 5 to 18 feet. Lime.
    Beaver Co. 2 to 7 feet. Lime.
    Butler Co. 2 to 5 feet. Impure.
    Cambria Co. 0 to 10 feet. Lime.
    Center Co. Thin, of little value.
    Clarion Co. Variable thickness. Lime.
    Clearfield Co. 3 to 15 feet. Lime.
    Elk Co. 2 feet. Lime.
    Fayette Co. 3 to 18 feet. Lime.
    Indiana Co. 0 to 10 feet. Lime.
    Jefferson Co. 3 to 15 feet. Lime.
    Lawrence Co. 2 feet. Unimportant.
    Somerset Co. Variable thickness. Unimportant.
    Westmoreland Co. 3 to 18 feet. Lime.

Pennsylvanian System—Continued.

Lower Freeport (Butler) limestone.
- Armstrong Co. Thin, of little value.
- Beaver Co. 3 to 9 feet. Lime.
- Butler Co. 3 feet. Unimportant.
- Cambria Co. 4 feet. Lime.
- Centre Co. 3 feet. Unimportant.
- Clarion Co. Thin, unimportant.
- Clearfield Co. 2 to 8 feet. Lime.
- Elk Co. 4 feet. Lime.
- Fayette Co. 2 to 4 feet. Unimportant.
- Indiana Co. 4 feet. Lime.
- Jefferson Co. 2 feet. Lime.
- Somerset Co. Thin, unimportant.
- Westmoreland Co. 2 to 4 feet. Unimportant.

Johnstown limestone.
- Cambria Co. 6 feet. Lime, cement.
- Centre Co. Thin, unimportant.
- Clearfield Co. 2½ feet. Lime.
- Elk Co. 2 to 6 feet. Of little value.
- Fayette Co. 8 feet. Not continuous. Lime.
- Indiana Co. 5 feet. Lime.
- Jefferson Co. 2½ feet. Lime.
- Somerset Co. 2 to 8 feet. Lime.
- Westmoreland Co. 8 feet. Lime.

Vanport (Ferriferous) (Clermont) limestone.
- Armstrong Co. 20 feet. Lime, flux, road metal.
- Beaver Co. 5 to 19 feet. Flux, lime, road metal. Important.
- Butler Co. 0-22 feet. Flux, lime, road metal. Very important.
- Centre Co. Thin, unimportant.
- Clarion, 10 to 20 feet. Lime, flux, road metal.
- Elk Co. 6 to 10 feet. Lime.
- Indiana Co. 4+ feet. Lime.
- Jefferson Co. 0 to 6. Lime.
- Lawrence Co. 0-23 feet. Flux, lime, road metal. Very important.
- McKean Co. 6 to 8 feet. Lime.
- Mercer Co. 8+ feet. Fairly important.
- Venango Co. 0-20 feet. Flux, lime, road metal. Important.

Benezette limestone.
- Elk Co. 1 foot. Of no value.

Pottsville series.

Upper Mercer (Mahoning, Upper Wurtemburg) limestone.
- Butler Co. Thin, unimportant.
- Lawrence Co. 2 to 4 feet.
- Mercer Co. 2 feet. Flux.

Mercer (Lower Mercer) (Lower Wurtemburg) limestone.
- Armstrong Co. 6 to 10 feet. Impure. Of little value.
- Beaver Co. 8 to 12 inches. Unimportant.
- Butler Co. Thin, unimportant.
- Lawrence Co. 2½ feet. Lime.
- Mercer Co. 2 to 4 feet. Lime, flux.

Pennsylvanian System—Concluded.
  Mauch Chunk series.
    Greenbrier limestone.
      Fayette Co. 3 to 40 feet. Road metal, lime.
      Fulton Co. Shales and limestone. Lime.
      Somerset Co. Important. Lime.
      Westmoreland Co. 3 to 40 feet. Road metal, lime.

Pocono series.
    Upper Meadville limestone.
      Crawford Co. 1 foot. Of little value.

    Lower Meadville (Marion Creek) limestone.
      Crawford Co. 2 feet. Lime.
      McKean Co. 5 feet. Impure, unimportant.

    Cassewago limestone.
      Crawford Co. 1 to 2 feet. Lime.
      Erie Co. 1 to 2 feet. Lime.

    Loyalhanna limestone.
      Blair Co. 40 feet. Road metal.
      Cambria Co. 45 feet. Paving blocks.
      Fayette Co. 60 feet. Ballast, paving blocks.
      Indiana Co. 45 feet. Paving blocks.
      Somerset Co. Lime. Road metal.
      Westmoreland Co. 60 feet. Ballast, paving blocks.

    Undifferentiated limestones.
      Clinton Co. Thin. Of little value.
      Luzerne Co. 12 to 15 inches. Lime.
      Potter Co. Thin. Of little value.
      Sullivan Co. 12 feet. Impure. Lime.

CHAPTER VIII.

TRIASSIC LIMESTONES.

The Triassic strata of Pennsylvania in the form of a curved band about 10 to 40 miles wide extending across the State from New Jersey to Maryland and contained within Northampton, Lehigh, Bucks, Berks, Lebanon, Dauphin, Lancaster, York and Adams counties consist mainly of shales and sandstones. Some thin impure fine-grained interbedded limestones are developed locally but are of no particular value. Of considerable value are some unique limestone conglomerates or limestone breccias that have been noted in a number of localities, especially at or near the northwestern boundary and near the base of the Brunswick formation. This type of rock is variable in character and distribution and grades into a quartz conglomerate or into a sandstone. In certain places it has been possible to map a Brunswick conglomerate and even to differentiate cartographically the siliceous and the calcareous phases. Elsewhere the conglomerate is extremely local, occurring as thin lenses and containing pebbles of shale, sandstones, and limestones in a mud cement. Near the surface the limestone fragments may have been removed by solution leaving open cavities. Some of the conglomerate lenses are several hundred feet thick.

Potomac marble.

The conglomerates in which all or nearly all the pebbles are limestones are very striking and from their occurrence along the Potomac River a short distance east of Harpers Ferry have received the name Potomac marble. Along the Potomac River the limestone pebbles are set in a matrix of red sandy shale.

In Pennsylvania the Potomac marble has been observed in a number of places but in few places does it have the brilliant color contrasts exhibited at the type locality. More commonly both the fragments and the matrix are dull gray or greenish gray. Some typical exposures of the rocks can be seen near Springtown, Bucks County; near Center Valley, Lehigh County; along Schuylkill River a few miles below Reading, Berks County; northeast of Bainbridge, Lancaster County; along Yellow Breeches Creek, 2 miles north of Lisburn, along Susquehanna River near Marsh Run, and near Dillsburg, York County.

On the whole the Potomac marble does not possess much value as it is apt to be too impure to be desirable for flux or lime, and the fragments too feebly cemented for use as a building stone. In places, however, ornamental stone for interior use might be obtained. The only places in the State, as far as known, where this stone has been utilized are near Dillsburg, York County, and near Klapperthall, Berks County. In both places it has been used for agricultural lime.

Frazer[77] describes a quarry 1 mile northwest of Dillsburg where the stone was quarried and burned for agricultural lime. In Report M3 (pp. 79-80) the following analyses of this same type of stone from quarries, just north of Dillsburg, are given:

Analyses of Potomac marble from Welty's quarries, near Dillsburg.

CaO	44.950	44.220	47.000	42.940	43.920
MgO	5.275	6.403	3.845	3.045	2.929
FeO	1.179	.864	.585	1.098	2.304
MnO	trace	trace	trace	trace	trace
Al_2O_3	2.460	2.320	1.690	2.680	5.090
S	.004	.003	.004	.003	.005
P	.011	.012	.003	.013	.031
CO_2	31.040	34.030	34.985	30.072	17.020
H_2O	1.460	1.150	1.270	1.160	1.720
Insoluble residue	14.010	10.890	10.460	18.580	27.010
	100.389	99.892	99.842	99.591	100.029

The ignited insoluble residues contain:					
SiO_2	11.603	8.766	7.710	13.144	25.320
Fe_2O_3	.039	.148	.211	.126	.113
Al_2O_3	.236	.126	.231	.524	.205
CaO	.838	.634	1.238	2.560	.433
MgO	.666	.465	.819	1.777	.304

"Welty's quarries, on the Dillsburg branch of the C. V. R. R. about a third of a mile north of the depot at Dillsburg. Mesozoic limestone.

"Brecciated; rather hard and tough, with irregular fracture; color, generally greenish grey. Portions of the mass consist of a white saccharoidal limestone. Some of the specimens show beautiful dendritic impressions."

In Report M (p. 77) another analysis of this stone from near the same locality is given as follows:

"$CaCO_3$ 73.180, $MgCO_3$ 4.370, Fe .520, Insoluble residue 21.500.

"In bottom of M'William's Slope, one mile northeast from Dillsburg.

"Limestone conglomerate, crystalline; color greenish gray."

Berks County

The most extensive development of the Triassic limestone conglomerate is along the northwest boundary of the Triassic strata in the vicinity of Reading, Berks County. The most easterly locality is at Clayton. It appears at the surface just east of Bechtelsville and overlies the ore in the Boyertown magnetite iron mines. From

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[77] Pennsylvania Geol. Survey, Rep. CC. p. 225.

Athol (Amityville) to Stonersville it is unusually well-developed, forming the surface rock over almost the entire northern half of Amity township. Another lens with a width of outcrop of about 2,000 feet appears near Antietam Creek about 2 miles south of Jacksonwald and extends westward through Neversink and Fritz Island to a point a short distance beyond the Schuylkill River. It forms most of Poplar Neck and the peninsula lying to the west and good exposures are seen in some of the railroad cuts. West of the Schuylkill River it has been observed in a few places but particularly at the old Wheatfield Ore Banks, three-quarters of a mile east of Fritztown.

In the Berks County localities the conglomerate varies greatly. In some places it has a large admixture of sandstones and shale fragments. The size and shape of the fragmental material and the color also vary.

Near Klapperthall about 2 miles southeast of Reading an attractive variety of the Potomac marble outcrops along the railroad. Angular fragments of white, gray, mottled and reddish crystalline limestones are enclosed in a red sand matrix. Some specimens from the locality have been found to take a high polish and are especially handsome. The rocks near the surface are somewhat broken by frost action so that it might be difficult to secure large building blocks but it is probable that better stone could be obtained at greater depth. An illustration of this stone is given on page 337. It is possible that at this locality and perhaps at some other localities attractive decorative stone for interior work might be obtained. The stone is almost identical with the marble formerly quarried along the Potomac River in Maryland and Virginia except that the fragments are somewhat smaller, averaging less than an inch in diameter.

York and Lancaster Counties.

Prof. M. H. Bissell furnishes the following brief descriptions of a few localities in York and Lancaster counties:

"Excellent exposures of this conglomerate may be seen in the steep bank of Yellow Breeches Creek some two miles north of Lisburn, and in the Pennsylvania Railroad cuts on the west bank of the Susquehanna River two to three miles southeast of New Cumberland.

"In the first of the above-mentioned localities a cliff ten to twenty feet or more in height is made up of great masses of conglomerate with interbedded strata of sandstone and shale. Some of the conglomerate is exceedingly coarse, containing bowlders two feet in diameter, with which are mixed, without any suggestion of sorting, fragments of heterogeneous sizes down to small pebbles. The material is partly limestone, partly quartzite and red sandstone. Some of it is rounded and some quite angular. Although thick beds of such heterogeneous material show no sign of sorting, in places they overlie beds of sandstone with almost no conglomerate, and even thin strata of shale are interbedded with the coarsest conglomerate.

"South of the Paleozoic-Triassic contact on the west bank of the Susquehanna, below Marsh Run, the breccia-like character of the Potomac marble is more strikingly shown. Here the rock is a limestone breccia containing angular fragments of all sizes up to about one foot in diameter. (Plate XIV A) Many of the fragments are much flattened, but are not arranged with their long axes parallel. Although limestone is the predominating material, white and yellow quartzite, red sandstone and shale, and schist are found as fragments. Near the signal tower in the railroad cut, a bed of such breccia or conglomerate ten feet thick is overlain and underlain by red sandstone.

"A very extensive surface exposure, which, however, does not afford any vertical sections, occurs along the eastern margin of the Triassic belt east of the Susquehanna River in the vicinity of Bainbridge, especially along Conoy Creek."

Since this Triassic conglomerate, Potomac marble, has never been quarried in Pennsylvania as a building or ornamental stone but has been rather extensively quarried in Maryland, the following pages descriptive of it are abstracted from a report on "The Character and Distribution of Maryland Building Stones."[78]

Potomac Marble in Maryland.

"The most interesting building material in the entire state of Maryland is the "Potomac marble," "calico rock" or "Potomac breccia," which has been used occasionally for the greater portion of the century. The chief interest in this rock arises from the fact that it is the only true conglomerate or breccia marble that has ever been utilized to any extent in the United States.[79]

"This conglomerate is found in several places along the eastern slope of the Blue Ridge and is most extensively quarried in the vicinity of Point of Rocks, Frederick county near Washington Junction on the Baltimore and Ohio Railroad. The quarries are small affairs, which have been operated spasmodically. The one in operation at the present time is located about a mile east of the Washington Junction station on a spur which runs northeasterly from the Metropolitan Branch.

"This rock was first brought into notice by Mr. B. H. Latrobe, Superintending Architect in the construction and repair of the Capitol and White House before and after the war of 1812. In his report on the public buildings, read February 14, 1817,[80] Mr. Latrobe gives the first account of the use of this marble as a building stone, as follows: 'For the columns, and for various other parts of the House of Representatives, no free-stone that could be at all admitted has been discovered. Other resources, therefore, were sought after. A stone hitherto considered only as an encumbrance to agriculture, which exists in inexhaustible quantity at the foot of the most southeasterly range of our Atlantic mountains—probably along the greatest part of their extent, but certainly from the Roanoke to the Schuylkill, and which the present surveyor of the capitol, and

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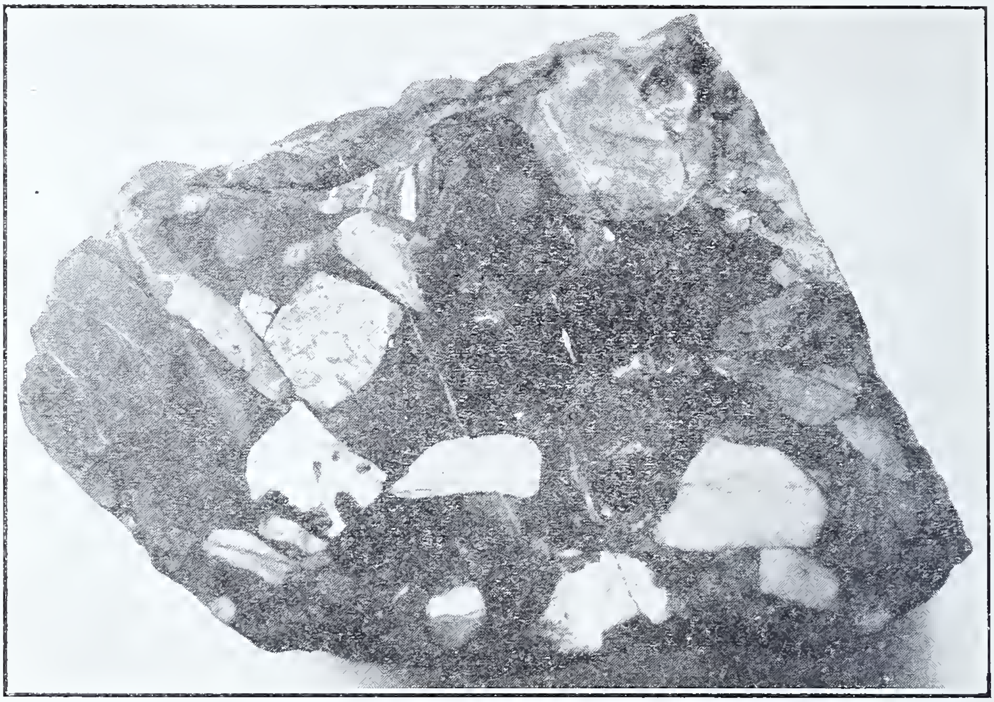
[78] Maryland Geol. Survey, Vol. 2, pp. 125-241. 1898.

[79] Merrill, G. P. "Stones for Building and Decoration," New York, John Wiley and Sons, 1891, p. 92.

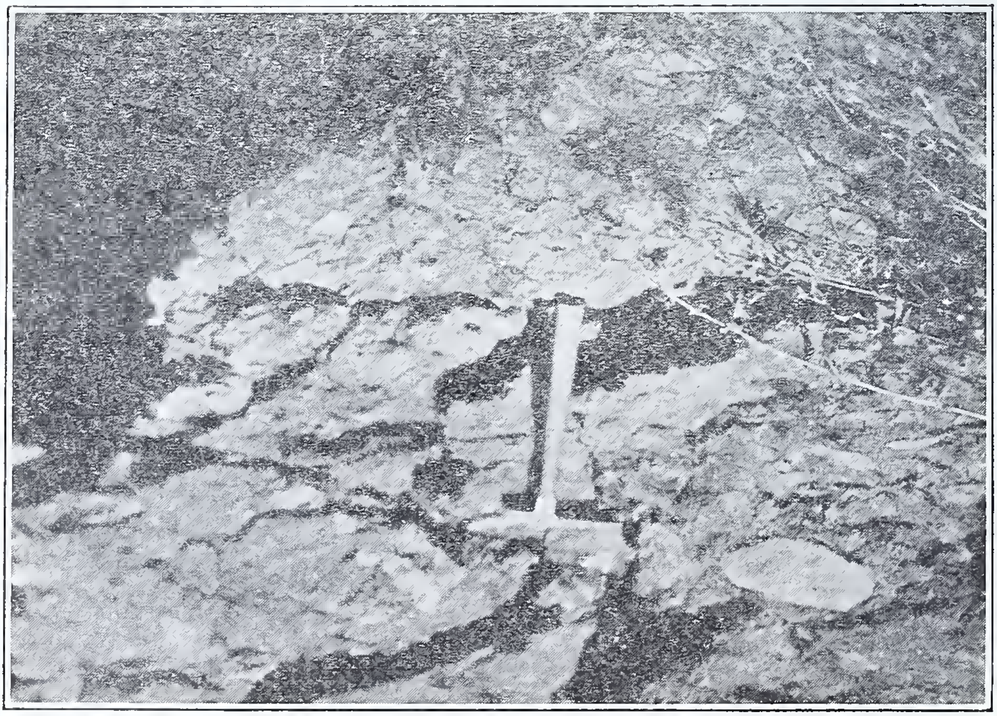
[80] Senate Documents, 14th Congress, 2nd Session, No. 101, pp. 3 and 6.

PLATE XV.



A. Polished specimen of Potomac marble, Reading.

(One-half natural size)



B. Triassic limestone conglomerate, southeast of New Cumberland.

probably others, had many years ago discovered to be a very hard, but beautiful marble— this stone was examined, and, after much labor and perseverance, has been proved to answer every expectation that was formed, not only of its beauty, but of its capacity to furnish columns of any length, and to be applicable to every purpose to which colored marble can be applied.

'The present commissioner of public buildings has, therefore, entered into a contract for all the columns, and progress has been made in quarrying them. They may be procured each in a single block should the transportation be found convenient.

'A block of one of the pilasters lies ready to be brought down to Washington, and will, probably, arrive in a few days. The quarries are situated in Loudoun county, Virginia, and Montgomery county, Maryland.'

"The columns which were then procured are still standing in the old House of Representatives, now used for the sittings of the Supreme Court. The quarries whence they were obtained have never been fully developed, although Mr. Latrobe thought that he had found in the newly discovered marble of the Potomac an inexhaustible resource of the most beautiful building materials situated easily accessible by water. There is some doubt as to the exact location of the particular source of these blocks used in the capitol, although they were monoliths of considerable size for the time and the primitive means of transportation.

"A few years later in his paper on the geology of the Southern States the Rev. Elias Cornelius[81] gives the following account of this brecciated limestone:

'It is also in the valley of this river (Potomac), and not far from its famous passage through the Blue Ridge, that immense quarries of beautiful breccia have been opened. This rock was first brought into use by Mr. Latrobe, for some years employed by the government as principal architect. It is composed of pebbles, and fragments of siliceous and calcareous stones of almost every size, from a grain, to several inches in diameter, strongly and perfectly cemented. Some are angular, others rounded. Their colors are very various, and often bright. Red, white, brown, gray and green, are alternately conspicuous with every intermediate shade. Owing to the siliceous stones which are frequently imbedded through the mass, it is wrought with much difficulty; but when finished, shows a fine polish and is unquestionably one of the most beautifully variegated marbles, that ever ornamented any place. It would be difficult to conceive of anything more grand than the Hall of the Representatives, in the Capitol, supported at it is by twenty or thirty pillars formed of the solid rock, and placed in an amphitheatrical range: each pillar about three feet in diameter, and twenty in height. Some idea of the labor which is employed in working the marble may be formed from the fact, that the expense of each pillar is estimated at five thousand dollars. The specimens in your possession, are good examples of its general structure, but convey no adequate idea of its beauty.'

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[81] On the Geology, Mineralogy, Scenery, and Curiosities of Parts of Virginia, Tennessee, and the Alabama and Mississippi Territories, etc., with Miscellaneous Remarks, in a letter to the Editor, vol. 1, Amer. Jour. Sci., New Haven, 1819, p. 216.

"The words of commendation and the beauty of the columns of the Capitol led the regents of the Smithsonian Institution to investigate the locality and to consider the availability of this rock for the building of the Smithsonian Institution. Accordingly in the spring of 1847 Dr. David Dale Owen visited these quarries, which, on the whole, he found were worthless for the purpose in hand.

"At the present time the work in the Potomac marbles is carried on almost exclusively by the Washington Junction Stone Co., which quarries both sandstone and Potomac marble. The former is obtained in good size blocks but the latter is wrought almost entirely in small slabs. The marble is taken from a small opening about half a mile southwest of the quarry buildings. The conglomerates under discussion belong in the Newark formation, which extends along the western border of the Piedmont Plateau from Connecticut and New York southward. The development of the Potomac marble within the Newark is not great and there are but few exposures within the state. It is sparingly developed north of Frederick, a mile south of Thurmont and only barely represented at Point of Rocks on the eastern slopes of the Catoctin Mountain. According to Mr. Keith[82] this limestone conglomerate occurs in lenses or wedges in the sandstone ranging from 1 foot to 500 feet in thickness, or possibly even greater. They disappear through complete replacement by sandstone at the same horizon. The wedge may thin out to a feather edge or may be bodily replaced upon its strike by sandstone; one method is perhaps as common as the other.

"The conglomerate is made up of pebbles of limestone of varying size which sometimes reach a foot in diameter, although usually averaging about two or three inches. The fragments, which are both well rounded and angular, range in color from gray to blue and dark blue, and occasionally pebbles of quartz, chloritic schists and white crystalline marble occur. All are embedded in a red calcareous matrix mixed with a greater or less amount of sand. The pebbles are very similar to the magnesian limestone of the Shenandoah formation, developed in the Frederick and Hagerstown valleys and to the rocks of the complex which forms the Catoctin Mountain. Occasionally pebbles show evidences of having been decayed even before they became a part of the conglomeratic mass, but this may be due to their greater solubility, since the matrix does not show a corresponding degree of decomposition.

"The bedding so far as it has been observed is irregular and of little importance in the quarrying of the rock, the lenticular character of the beds having far more importance than the position of the individual pebbles within the mass. In the same way the jointing is also a relatively subordinate feature since the different degrees of cohesion between the parts of the pebbles and that between the pebbles and the matrix play an important part in determining along what planes a rupture will take place. The texture shows a wide variation in the size of the grains, in the character of the material composing them, and in the relative amount of matrix between the grains and pebbles. This wide range in the size of the particles and in their abundance leads to many difficulties in polishing the rocks, but the difference between the hardness of the limestone and that of the quartz pebbles is particularly a source of expense and annoyance, since the hard quartz pebbles break away from the softer parts in which they lie, leaving numerous cavities to be filled with colored wax or shellac. This difference in the hardness and material of the pebbles, together with the conglomeritic character of the mass excludes the use of hammers and chisels. Any satisfactory quarrying of the blocks must be done with saw and abrasive materials. It is this difficulty in the working, together with the fragile nature of the stone itself, which has kept it from the conspicuous place in the market, which its oddity and beauty deserve.

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[82] Keith, Arthur, Geology of the Catoctin Belt, 14th Ann. Rept. U. S. Geol. Surv., part II, p. 346, Washington, 1894.

"The chemical composition of breccia can scarcely be determined from a single analysis, and the figures obtained from an average of several analyses may be of little account. The values obtained depend very largely on the accuracy of the analyst, the fineness of the grain, the homogeneity of the specimens and the number of samples taken to make an average test. Higgins[83] gives the following as 'the average of various analyses made of the Breccia marble, or Calico limestone, found in Montgomery, from which the pillars in the House of Representatives at Washington are made:'

Sand	12.25
Iron and clay	1.00
Lime, as carbonate	70.50
Magnesia	15.00
Other constituents not worthy of mention	0.25
Total	99.00

"This is probably of little value in itself and should have no weight in estimating the value of the marble. The stone is particularly suited to mosaic work and interior decorations, and should not attempt any competition as a structural material with the stones now in common use.

"The influence of microscopic structures in a stone like this breccia is more than over-balanced by the variations in the larger structural features of the rock. If the microscope or hand lens shows that the stone is sufficiently fine and homogeneous to take a good polish with few minute irregularities on the surface that is sufficient, still experience clearly shows that this rock will take a good polish and that it will withstand any pressure to which it may be subjected as an ornamental or decorative stone.

"This unique material deserves to be fully exploited and pushed as a novelty in the highest class of interior furnishings. It is believed that a demand might be created for this stone in some of the best work which is done in New York, Philadelphia, Washington and other large cities, where there is a call for materials which are suitable for floors and other interior decorations, striking in color and texture and of pleasing contrasts."

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[83] Second Rept. Jas. Higgins. State Agr. Chemist, Annapolis, 1852, p. 39.

CHAPTER IX

SUMMARY AND FUTURE PROSPECTS OF THE LIMESTONE INDUSTRIES OF PENNSYLVANIA.

In the foregoing pages descriptions of the various limestones of the State have been given. It has been shown that there is a wide variety, representing almost every type of limestone. Some of the varieties are unexcelled anywhere whereas others are of poor quality and cannot successfully compete with better grade stone from other States. Cement and lime made from Pennsylvania limestones are shipped in large quantities to other States and even to foreign countries but, on the other hand, limestone and marble for building and decorative purposes are brought into Pennsylvania from both nearby and remote localities. Much fluxing limestone from other States is also used in the Pittsburgh district but this is partly because transportation charges are less than for stone from the eastern part of the State.

Limestones of some kind are present in almost every county although they are sparingly represented in the northern third of the State. The entire northern tier of counties is markedly deficient and in addition in a number of other counties, particularly in the northeastern part, the limestone strata are few and thin and of little economic importance. Yet even in those localities limestones have been quarried locally for agricultural lime and occasionally for other purposes.

Building and decorative purposes.—For a number of years, in fact ever since the extension and improvement of railroad transportation made available the excellent limestone from Indiana and the superior marble from New England, Georgia, and Alabama, and since the decided increase in the cost of labor the quarrying of Pennsylvania limestones and marbles for building and decorative purposes has been on the decline. At present very little building stone is being produced and practically all that is quarried is for local use for foundations, walls, and other rough construction. Numerous houses built of Pennsylvania limestone can be seen throughout the State but nearly all of them were built before the Civil War and many date back to the earliest settlement of the State.

Marble was at one time quarried in a number of places in Montgomery and Chester counties and shipped into Philadelphia but no quarry in the State is furnishing marble to the building trade.

Limestone and marble for building purposes are readily available but they have not been in demand in recent years. The few people who now build houses of limestone are likely to specify the Indiana limestone that is so favorably known and so widely used throughout the entire country. The large well-equipped quarries of that State are so able to supply the desired quantity, in the specified sizes and on short notice that it would be difficult for a Pennsylvania firm to compete. Further the limestones that should furnish the best building stones lie in the southeastern part of the State, in the belt where the strata have been greatly folded and, in most instances, rather badly shattered. The folding of the strata increases the cost of quarrying and the breaking of the rocks renders it more difficult to obtain stone of dimensional sizes and increases the amount of waste. It therefore seems that there is little prospect of the State materially increasing its output of limestone for building purposes in the near future.

In regard to marble somewhat similar conditions prevail. Unusually attractive marble can be obtained in the limestone belt that extends from Montgomery County westward through Chester, Lancaster, and York counties and into Adams County but it would require a considerable investment of capital to open a quarry and equip a marble plant and the past history of marble quarrying in the region does not offer much encouragement. A property north of York that was explored by diamond drill contains some beautiful stone and it seems as though it might be worked with profit inasmuch as most of the refuse would be in demand for high grade flux or for the manufacture of chemical lime.

The "Potomac marble" of the Triassic that is developed in Berks, Cumberland, and York counties is an unusual stone that compares favorably with many of the highly colored foreign marbles but it is problematical as to whether it could be worked economically.

Crushed stone.—The demand for crushed limestone for concrete, road metal, and railroad ballast has been steadily increasing and the quarries of the State have more than supplied the State's needs. Some material has been furnished to adjoining States but seldom is crushed stone shipped far.

The Cambro-Ordovician and Helderberg limestones of the central and southeastern counties are particularly good for these purposes and it is rather rare to find limestones in these formations that fail to meet the rigid specifications of the State Highway Department.

The Carboniferous limestones of the southwestern and west central counties are less satisfactory but there are many places where they yield suitable material.

There is no indication that the demand for crushed limestone is likely to decrease and even though the rapid increase of the past decade should continue there will be no difficulty in meeting the demand.

Pulverized stone.—Pulverized limestone for fertilizing purposes and for use as a filler has not been produced in Pennsylvania in large quantities in the past but the output is slowly increasing. Limestone of suitable composition is not lacking.

The glass, ceramic, paint, and other manufacturing industries requiring limestone have been able to secure satisfactory material at many places throughout the limestone sections of the State.

Flux.—Almost any kind of limestone can be used for flux and during the time that iron ore was mined and smelted in almost all parts of the State local limestones were used almost universally. With the change that has come about by which practically all the iron mines were abandoned, the small furnaces torn down and the iron and steel industries concentrated in a few places and dependent upon ores originating from without the State there has been a demand only for limestones of the best grade. Although Pennsylvania can and does produce the two desirable types of limestone demanded —low silica, high calcium stones and low silica dolomites—considerable limestone flux is shipped into the State. The Pittsburgh district in particular obtains its low silica dolomite primarily from West Virginia as no satisfactory stone of this type can be obtained from the western part of the State. The Vanport limestone that is developed over a large area north and northeast of Pittsburgh furnishes only part of the high calcium stone needed and supplies are brought in large quantities from other States, particularly Michigan.

The iron and steel plants of the eastern part of the State obtain nearly all of their fluxing limestones locally although even here material is shipped from adjoining States. For example the Bethlehem Steel Co. operates a large quarry at McAfee, N. J. to supply high grade limestone for its Bethlehem plant.

Notwithstanding the fact that Pennsylvania does not supply all the fluxing limestones used within the State, the production of such material by the quarries of the State is large and will certainly continue. The reserves are adequate to supply the demands indefinitely.

Cement.—From the beginning of the cement industry in this country, Pennsylvania has been the leading producer and for many years produced more Portland cement than all the other States. At present it produces about one-fourth the entire production of the United States.

This enviable position has been maintained because of the occurence in Lehigh and Northampton counties of the best cement limestone to be found anywhere. Portland cement can also be made from other limestones but with the exception of a few companies that use the Vanport limestone of the western part of the State and the manufacture of cement from furnace slag, the cement industry is still confined to the Lehigh district where it originated. Limestones suitable for cement are found in several other places but it is doubtful whether there are many other sections in the State where Portland cement could be manufactured with profit on account of the keen competition that would result with the well-established, greatly-favored section of Lehigh and Northampton counties.

The supply of cement rock in the Lehigh district is so large that Pennsylvania will long maintain its preeminent position. The situation in the western part of the State where the Vanport limestone is utilized is not so favorable but if underground mining methods are employed, as have already been done, Portland cement will be produced there for many years.

Lime.—Although Pennsylvania does not lead in the production of lime, nevertheless it is among the leading States. Lime for practically every purpose for which it is used is made within the State. Although most is used here, large quantities, especially of the better grades, are shipped beyond its borders.

Agricultural lime for the soil has been produced in every section where limestones occur. Small lime kilns, most of them now in ruins, can be found in every limestone section of the State. Their decadence is owing to diminished use of agricultural lime by the farmers and the change from the small plant used intermittently to the larger better equipped operations running continuously. Many of the limestones of poor quality are no longer utilized as the larger plants are built where good stone is available. Agricultural lime is still produced widely throughout the State and will long continue to be produced.

Lime for plaster and mortar mainly comes from the central and southeastern counties where there are a number of large operations. The Cambro-Ordovician and Helderberg limestones are used.

Chemical lime used in the manufacturing industries must conform to very rigid specifications and there are only a few districts where it is produced. Most of this is made from the unusually high grade Cambro-Ordovician limestones of Chester, Lancaster, York, Lebanon, and Centre Counties. The Helderberg limestones also yield chemical lime in a few localities, as for example, near Frankstown, Blair County.

The lime industry of the State should continue to hold the prominent position it now enjoys and should increase if the demand grows.

Magnesia.—The extraction of magnesium oxide and magnesium carbonate from high grade dolomites is a local industry developed in Montgomery and Chester counties. The supply of suitable stone is probably not large; yet there are other sections where it occurs, and doubtless similar stone might be found in a number of localities if careful search was made.

PRODUCTION STATISTICS.

In 1922 the reported daily capacity of 741 kilns in Pennsylvania lime plants was 3,555 tons. Of 476 kilns whose type is recorded 133 are pot kilns, 223 patent, 3 gas, 2 rotary, and 115 field kilns. These 476 kilns use fuel as follows: coal 383, coke 84, Producer gas 5, oil 3, wood 1.

The following tables were compiled from Mineral Resources of the United States, published annually by the United States Geological Survey.

Limestone sold in Pennsylvania and in the United States, 1919-1923.

		NUMBER OF ACTIVE PLANTS	BUILDING						Rubble		Riprap		CRUSHED STONE			
			Rough Construction		Rough Architectural		Dressed						Concrete and road metal		Railroad ballast	
			Short tons	Value	Cubic feet	Value	Cubic feet	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1910	Pa.	------	------	------	------	$103,295	------	$118	------	$3,314	------	$1,714	------	$844,944	------	$495,002
	U.S.	------	------	------	------	2,276,574	------	2,995,450	------	820,002	------	1,348,172	------	11,376,931	------	4,288,431
1911	Pa.	------	------	------	------	89,798	------	4,545	------	6,595	------	4,201	------	1,070,509	------	390,938
	U.S.	------	------	------	------	1,997,757	------	2,724,043	------	640,308	------	1,561,273	------	11,928,385	------	4,619,972
1912	Pa.	------	------	------	------	144,424	------	1,258	------	8,730	------	1,745	------	897,787	------	285,312
	U.S.	------	------	------	------	2,178,870	------	2,873,026	------	639,674	------	1,182,451	------	12,765,298	------	4,854,201
1913	Pa.	------	------	------	------	106,690	------	840	------	8,600	------	8,391	------	1,086,893	------	419,579
	U.S.	------	------	------	------	1,943,064	------	2,566,275	------	440,480	------	1,331 423	------	13,520,800	------	5,551,415
1914	Pa.	------	------	------	------	67,869	------	1,215	------	6,970	------	2,436	------	1,071,887	------	291,977
	U.S.	------	------	------	------	1,642,627	------	2,254,227	------	423,336	------	1,123,123	------	14,094,533	------	3,967,348
1915	Pa.	------	------	------	------	49,150	------	695	------	4,637	------	2,057	------	1,053,814	------	172,708
	U.S.	------	------	------	------	1,488,945	------	2,567,256	------	306,116	------	1,305,636	------	13,498,739	------	3,604,256
1916	Pa.	------	------	------	------	44,946	------	(a)	------	(a)	------	4,824	------	916,959	------	111,202
	U.S.	------	------	------	------	1,305,771	------	3,282,434	------	297,772	------	1,257,457	------	14,067,631	------	3,650,647
1917	Pa.	------	------	------	------	54,207	------	(a)	------	(a)	------	3,637	------	998,938	------	114,650
	U.S.	------	------	------	------	2,083,886	------	2,031,480	277,376	270,327	1,007,357	18,679,213	------	14,146,603	------	3,394,495
1918	Pa.	------	------	------	303,343	37,054	------	------	1,743	1,792	(a)	(a)	719,386	942,539	86,737	74,261
	U.S.	------	------	------	2,561,600	943,735	1,136,435	1,322,919	106,327	109,369	1,118,109	969,276	13,610,947	12,371,502	5,509,911	3,901,682
1919	Pa.	241	------	------	------	------	------	------	36,771	59,630	4,944	9,488	1,660,402	2,228,902	181,383	185,976
	U.S.	1,192	------	------	4,006,620	2,184,891	1,470,600	2,073,445	328,295	430,113	833,622	908,595	16,956,886	17,887,168	4,805,060	3,822,038
1920	Pa.	267	------	------	222,240	41,901	------	------	7,760	14,012	8,640	10,651	1,879,750	2,989,994	124,590	207,933
	U.S.	1,269	------	------	5,955,320	4,239,912	1,586,830	3,957,954	274,630	425,279	892,610	907,616	20,419,130	25,349,446	5,388,670	5,350,353
1921	Pa.	279	24,540	$40,390	------	------	------	------	------	------	(a)	(a)	2,392,110	3,463,572	99,410	139,371
	U.S.	1,251	183,000	253,786	2,458,780	1,699,783	3,407,910	5,933,017	188,000	280,067	941,730	1,003,399	23,985,790	27,903,303	4,734,620	4,329,135
1922	Pa.	279	36,040	50,709	------	------	------	------	(a)	(a)	------	------	2,874,000	3,364,085	114,070	142,525
	U.S.	1,292	210,690	271,343	4,352,030	2,577,416	5,843,550	9,570,114	286,340	470,264	1,010,850	925,760	27,906,450	28,966,511	4,879,850	4,258,368
1923	Pa.	280	29,160	38,648	------	------	------	------	2,300	2,903	------	------	3,007,310	4,231,112	64,590	73,756
	U.S.	1,437	210,310	238,805	5,031,840	3,184,932	7,192,810	12,797,358	327,180	484,771	1,536,570	1,451,670	33,382,210	35,925,709	8,004,340	6,615,045

(a) Statistics for Pennsylvania not published separately on account of few producers.

Limestone sold in Pennsylvania and in the United States, 1910-1923. (Continued.)

		Fluxing stone		Sugar factories		Glass factories		Paper mills		Agriculture		Other		Total	
		Long tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons (approximate)	Value
1910	Pa.	7,545,094	$3,735,060	-----	-----	-----	-----	-----	-----	-----	-----	-----	$121,137	-----	$5,394,611
	U.S.	18,203,882	9,345,733	-----	362,400	-----	-----	-----	-----	-----	-----	-----	1,122,560	-----	34,603,678
1911	Pa.	6,769,949	3,396,304	-----	-----	-----	-----	-----	-----	-----	-----	-----	152,160	-----	5,243,045
	U.S.	16,126,650	7,987,208	-----	300,717	-----	-----	-----	-----	-----	-----	-----	1,474,379	-----	33,897,612
1912	Pa.	8,540,211	4,361,677	-----	-----	-----	-----	-----	-----	-----	-----	-----	165,831	-----	6,017,308
	U.S.	20,190,554	9,937,772	-----	335,108	-----	-----	-----	-----	-----	-----	-----	1,516,962	-----	36,709,800
1913	Pa.	8,180,056	4,206,797	-----	-----	-----	-----	-----	-----	-----	51,416	-----	137,244	-----	6,189,145
	U.S.	22,620,961	11,103,989	-----	387,724	-----	-----	-----	-----	-----	493,718	-----	1,051,062	-----	38,745,429
1914	Pa.	6,467,961	3,563,571	-----	-----	-----	-----	-----	-----	-----	72,789	-----	97,054	-----	5,270,458
	U.S.	15,298,756	7,890,369	-----	323,796	-----	-----	-----	-----	-----	688,961	-----	1,158,525	-----	33,894,155
1915	Pa.	8,625,636	4,799,546	-----	-----	-----	-----	-----	-----	-----	117,903	-----	164,977	-----	6,367,446
	U.S.	18,998,723	9,672,347	-----	381,038	-----	-----	-----	-----	-----	893,530	-----	1,404,434	-----	35,229,866
1916	Pa.	10,019,046	6,768,374	-----	-----	-----	74,990	-----	-----	73,301	129,574	-----	115,219	-----	8,167,639
	U.S.	26,623,508	13,946,882	369,028	369,694	193,028	181,322	-----	-----	1,043,876	1,109,208	-----	1,639,639	-----	41,319,871
1917	Pa.	9,840,305	8,790,058	-----	-----	-----	109,862	-----	(a)	138,323	261,396	-----	234,449	-----	10,589,524
	U.S.	25,574,146	18,679,213	530,612	666,138	293,152	344,479	101,305	95,582	1,040,248	1,352,397	-----	2,276,323	-----	46,263,379
1918	Pa.	8,689,007	10,473,227	-----	-----	51,185	93,653	29,404	36,670	131,061	325,982	258,562	326,284	-----	12,302,255
	U.S.	23,862,029	23,427,736	435,555	649,589	202,211	332,744	100,247	117,829	1,091,918	1,626,292	4,653,699	3,642,497	-----	49,453,036
1919	Pa.	7,607,131	9,547,016	-----	-----	53,509	100,316	(a)	(a)	65,612	243,529	122,002	229,843	10,665,500	12,640,411
	U.S.	18,928,886	19,271,674	503,835	821,912	166,103	278,467	92,421	129,649	1,392,914	2,409,460	3,080,101	2,909,791	49,759,800	53,171,701
1920	Pa.	8,228,970	11,967,561	-----	-----	67,690	158,626	(a)	(a)	70,710	281,196	112,910	203,642	11,531,540	15,913,109
	U.S.	22,301,060	26,475,763	637,090	1,200,394	196,150	400,873	139,880	256,278	1,364,260	2,724,209	4,432,170	4,435,342	59,230,000	75,655,260
1921	Pa.	3,510,780	4,041,152	-----	-----	49,570	110,351	(a)	(a)	97,090	333,354	102,320	196,138	6,713,240	8,346,138
	U.S.	9,503,830	9,428,767	570,840	1,019,288	118,970	232,715	120,460	223,601	1,311,520	2,355,339	2,383,280	3,087,394	45,621,000	57,749,594
1922	Pa.	5,699,180	5,569,056	-----	-----	63,950	126,244	22,790	28,344	110,390	339,761	131,710	227,266	9,736,470	9,848,290
	U.S.	16,687,740	14,208,457	371,430	634,511	166,070	291,854	149,430	264,130	1,195,000	2,150,435	3,317,430	3,808,764	58,928,660	68,397,927
1923	Pa.	9,037,150	8,616,237	-----	-----	62,440	114,342	27,280	35,868	95,170	329,210	233,150	311,017	12,558,550	13,753,093
	U.S.	22,823,340	20,333,939	474,530	875,774	197,380	301,403	266,740	326,054	1,278,770	2,160,249	4,625,510	4,877,468	76,701,360	89,620,097

(a) Statistics for Pennsylvania not published separately on account of few producers.

Hydrated lime sold in Pennsylvania and in the United States, 1910-1923.

		Short tons	Value
1910	Pa.	---	---
	U.S.	320,819	$1,288,789
1911	Pa.	---	---
	U.S.	304,593	1,372,057
1912	Pa.	---	---
	U.S.	416,890	1,829,064
1913	Pa.	---	---
	U.S.	493,269	2,205,657
1914	Pa.	---	---
	U.S.	515,121	2,239,916
1915	Pa.	---	---
	U.S.	581,114	2,457,602
1916	Pa.	126,890	585,847
	U.S.	717,382	3,626,988
1917	Pa.	142,254	974,936
	U.S.	709,157	4,643,094
1918	Pa.	133,583	1,126,957
	U.S.	620,216	5,342,113
1919	Pa.	166,282	1,607,090
	U.S.	777.408	7,061,146
1920	Pa.	169,639	1,884,787
	U.S.	853.116	9.287,562
1921	Pa.	135,917	1,311,678
	U.S.	792,970	7,421,637
1922	Pa.	172,179	1,571.709
	U.S.	1,106,063	9,868,980
1923	Pa.	177,836	1,740,209
	U.S.	1.225,928	12,229,598

Portland cement produced in Pennsylvania and the United States, 1910-1923.

		Production		Shipments		
		Active plants	Barrels	Barrels	Value	Average factory price per bbl.
1910	Pa.	25	26,675,978	---	$19,551,268	$0.75
	U.S.	111	76,549,951	---	68,205,800	.891
1911	Pa.	25	26,864,679	27,539 076	18,918,165	.687
	U.S.	115	78,528,637	85,012,556	69,109,800	.813
1912	Pa.	23	26,441,338	27,539,076	18,918,165	.687
	U.S.	110	82 438,096	85,012,556	69,109,800	.813
1913	Pa.	23	28,701,845	28,060,495	24.268,800	.865
	U.S.	113	92,097,131	88,689,377	89,103.975	1.005
1914	Pa.	20	26,570,151	25,985,106	20,944,787	.806
	U.S.	110	88,230.170	86,437,956	80,118 475	.927
1915	Pa.	20	28,648,941	28,188,450	20,252,961	.718
	U.S.	106	85.914.907	86,891,681	74.756.674	.860
1916	Pa.	20	27,325,147	28,748,546	27.915,298	.971
	U.S.	113	91.521,198	94,552.296	104.258,216	1.103
1917	Pa.	21	27,732,838	27,709.442	34,512,388	1.25
	U.S.	117	92,814,202	90,703,474	122,775.088	1.35
1918	Pa.	21	22,628,901	22,238,689	33,600.956	1.51
	U.S.	114	71,081.663	70,915,568	113,153,513	1.60
1919	Pa.	21	25,325,173	26.250,077	43.126,528	1.64
	U.S.	111	80.777,935	85.612,899	146.734.814	1.71
1920	Pa.	21	28,269,314	27,662.116	52,632.082	1.90
	U.S.	117	100,023,245	96,311,719	194,439.025	2.02
1921	Pa.	22	27,628,598	26.622,367	46,881 625	1.76
	U.S.	115	98.842,049	95,507,147	180,778,415	1.89
1922	Pa.	22	33,276,003	34,023.695	55,528,002	1.63
	U.S.	118	114,789,984	117,701,216	207,170,430	1.76
1923	Pa.	22	38,157,482	38,610,852	69,792,343	1.81
	U.S.	126	137,460,238	135,912,118	257,0[illegible]4,1[illegible]4	1.90

Lime produced in Pennsylvania and in the United States, 1915-1923.

		Number of plants	Number of kilns	Building		Agriculture		Paper mills		Chemical Uses								Total	
										Glass works		Tanneries		Metallurgy		Other chemical uses			
				Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
1915	Pa.	451	-----	284,239	$1,049,135	345,960	$995,703	50,657	165,135	-------	--------	11,804	$38,373	-------	----------	107,407	$344,201	901,549	$2,947,058
	U.S.	905	-----	1,136,696	4,812,710	653,686	2,163,874	216,819	782,396	-------	--------	47,104	190.864	-------	----------	492,870	1,653,750	3,589,699	14,336,756
1916	Pa.	335	-----	212,095	962,266	318,722	1,036,222	69,474	245,601	-------	--------	17,757	70,955	56,404	$197,436	131,201	451,759	972,343	3,857,553
	U.S.	778	-----	1,509,968	7,859,614	613,527	2,224,401	353,187	1,461,412	-------	--------	59,919	278,003	180,018	712,101	621,120	2,298,246	4,073,433	18,509,305
1917	Pa.	222	-----	162,658	1,034,504	246,608	1,218,316	78,181	377,933	9,954	$58,707	24,236	138,305	90,688	445,609	129,791	705,594	936,209	5,900,016
	U.S.	595	-----	1,313,493	8,713,845	488,297	2,475,731	355.768	2,098,433	60,624	316,280	66,629	408,976	209,976	1,141,647	772,787	4,476,191	3,786,364	23,807,877
1918	Pa.	162	-----	126,432	1,020,744	200.073	1,343,636	77,512	527,313	1,281	7,675	26.006	196,791	87,327	599,136	84,562	595,152	801,834	6,654,407
	U.S.	496	-----	914,186	7,781,388	391,047	2,698,848	325,172	2,610.645	34,051	265,855	74,350	637.960	253,778	1,884,672	566,532	4,177,302	3,206,016	26,808,909
1919	Pa.	187	-----	165,906	1,571,238	232,831	1,706,027	73,761	537,691	3,986	29,618	11,416	88,629	84,489	530,923	204,210	1,696,659	779.608	6,181,710
	U.S.	537	-----	1,191,434	11,484 318	438,632	3,345.039	335,813	2,836,347	44,618	336,020	59,978	580,022	295,622	2,152,554	831,022	7,595,818	3,330,347	29,448,553
1920	Pa.	162	-----	148,378	1,625,471	202,830	1,792,948	56,572	506,578	4,242	40,802	21,245	198,706	89,689	675,529	260,140	2,669,800	784,083	7,519,147
	U.S.	515	-----	1,305,412	15,269,683	351 851	3,006,705	365.897	3,844,084	54,747	551,945	61,169	668,909	344,921	2,836,474	1,000,550	10,304,049	3,570,141	37,543,840
1921	Pa.	183	-----	137,139	1,261,494	152,667	1,183,361	46,977	390,334	2.690	21,734	6,003	50,073	59,572	432,897	103,737	898,882	509,891	4,247,509
	U.S.	520	-----	1,239,486	13,258 443	284,722	2,237,510	235,855	2,207,938	43,851	367,796	47,841	481,372	164,245	1,232,748	456,087	4,372,991	2,532,153	24.895,370
1922	Pa.	177	741	233,088	1,920,087	137,460	1,021,092	55,144	414,491	(a)	(a)	4,552	34,243	79,757	522,769	208,213	1,658.576	719,536	5,581,794
	U.S.	530	2,246	1,845,208	18,463.825	272,726	2,005,082	310,229	2,683,487	62,187	463,628	42,978	420,148	200,799	1,458,553	834,279	6,986,366	3,639,617	33,255,039
1923	Pa.	143	-----	287,595	2,563,641	112,011	838,010	36,239	287.103	1,361	12,495	8,195	68,066	133,288	954,645	194,150	1,648,770	772,839	6,172,732
	U.S.	467	-----	2,131,533	22,521,638	240,551	1,825,519	311,309	2,768,909	78,942	676,291	53,906	523,994	373,020	3,044,383	886,981	8,632,918	4.076,242	39,993,652

Lime consumed in Pennsylvania and in the United States, in short tons, 1916-1923.

	Sales	Shipments from State	Shipments into State	Consumption			
				Quick lime	Hydrated lime	Total	Per capita (estimated)
1916 Pa.	972,343	229,785	267,029			1,009,587	.12
1916 U.S.	4,073,433	2,063,213	2,050,876			4,061,096	.04
1917 Pa.	936,209	238,960	200,932	762,837	135,344	898,181	.10
1917 U.S.	3,786,364	1,794,189	1,784,707	3,068,838	708,044	3,776,882	.037
1918 Pa.	801,834	239,832	209,845	633,124	138,723	771,847	.085
1918 U.S.	3,206,016	1,566,616	1,553,959	2,574,872	618,487	3,193,359	.030
1919 Pa.	779,608	237,928	168,284	571,088	138,876	709,964	.081
1919 U.S.	3,330,347	1,529,001	1,524,613	2,550,162	775,797	3,325,959	.031
1920 Pa.	784,083	269,876	172,994	542,789	144,412	687,201	.078
1920 U.S.	3,570,141	1,704,741	1,700,034	2,713,544	851,890	3,565,434	.033
1921 Pa.	467,794	108,691	107,494	353,565	113,032	466,597	.05
1921 U.S.	2,453,313	1,238,866	1,236,464	1,698,805	752,106	2,450,911	.022
1922 Pa.	719,536	251,753	222,873	533,509	157,147	690,656	.076
1922 U.S.	3,639,617	2,043,754	2,037,939	2,530,967	1,102,835	3,633,802	.033
1923 Pa.	[illegible]	[illegible]	[illegible]	566,504	169,005	735,507	.08
1923 U.S.	4,076,243	2,221,660	2,213,807	2,844,969	1,223,421	4,068,390	.036

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